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Graphical Method of predicting Occultations. By Professor D. M. Y. Sommerville, Victoria Univ. Coll., Wellington, N.Z.

(*Communicated by the Secretaries.*)

§ 1. In investigating an occultation of a star by the planet Venus I was led to consider a development of a graphical method which, on account of the ease and rapidity with which it may be carried out and its surprising accuracy, seems to deserve a wider application.

The method closely follows the lines of the computation on Bessel's principles, in which the shadow is projected on the *fundamental plane* through the earth's centre perpendicular to the line joining the earth's centre to the star. Numerous applications of this graphical method are indicated by Buchanan,* but the essential feature of the method which I have used consists in projecting also the meridians and parallels of the earth's surface on the fundamental plane, and having a series of charts prepared once for all on orthogonal projection for elevations of the pole from 0° at intervals of 1° up to, say, 29° or 30°. For any occultation the appropriate chart will be used, in a manner like a computing form. With a radius of 10 inches it is often easy to read to the nearest minute of time for the beginning or ending at any station. The diagram also admits of a graphical construction of the various curves to be plotted on the chart, which will generally be sufficiently accurate for this purpose.

§ 2. It will perhaps be of interest to narrate the circumstances of the occultation referred to above, which occurred on 1918 March 2. Information of this occultation was received by the New Zealand Government Astronomer, Dr. C. E. Adams, in a letter

* Roberdeau Buchanan, *Mathematical Theory of Eclipses* (Philadelphia, 1904), §§ 38–44, 58–60, 62–63, 70–72, 77, 158–166, 204–205.

from the Hon. Secretary of the Leeds Astronomical Society, Private Arthur Burnet, of the British Expeditionary Forces, France. He wrote :—

"The star is No. 2895 in the Cape Catalogue (1900) = 7 Aquarii, magnitude 5·7. Its position reduced to 1918 March 2 is R.A. $20^h\ 52^m\ 28^s{\cdot}97$, Dec. 10° 0′ 45″ S. The planet is almost stationary in R.A. at the time, and the chord of occultation lies along the western limb. After making the necessary corrections for parallax, I get an occultation beginning in New Zealand at $4^h\ 25^m$ G.M.T., and ending at $5^h\ 48^m$ G.M.T."

The place of the star was reduced and the interpolations carried out by Dr. Adams, the following elements being obtained :—

Occultation of 7 Aquarii by Venus. Elements.

t_0 :	G.M.T. of ♂ in R.A. .	1918 Mar. $2^d\ 4^h\ 4^m\ 12^s$
α :	♀ and star R.A.	$20\ 52\ 28{\cdot}73$ *
δ :	♀ declination	$-10°\ 0′\ 36″{\cdot}90$
δ' :	star ,, ...	$-10\ 0\ 45{\cdot}04$ *
$\Delta\alpha$:	♀ hourly motion in R.A. . . .	$+\ 6{\cdot}07$
$\Delta\delta$:	♀ ,, ,, in decl. . . .	$-\ 20{\cdot}42$
p :	♀ equatorial horizontal parallax . .	$26{\cdot}40$
r :	♀ semidiameter	$25{\cdot}20$
μ_0 :	G.S.T. of ♂ in R.A.	$2^h\ 42^m\ 45^s$
λ_0 :	Principal meridian, W. of Greenwich .	$5\ 50\ 16$

$$y_0 = \frac{\delta - \delta'}{p} = +0{\cdot}3083 \qquad x' = \frac{\Delta\alpha}{p}\cos\delta = +0{\cdot}2264$$

$$y' = \frac{\Delta\delta}{p} = -0{\cdot}7734$$

From the diagram and also by actual computation it appeared that the occultation could only be visible in New Zealand south of Christchurch (see chart, fig. 3), but apparently the Lick Observatory would be well placed for an observation of the phenomenon. Consequently a cable message was dispatched to that observatory, and fortunately excellent observations were obtained.† The weather in New Zealand prevented any definite observations from being made. A comparison of the following figures will show the accuracy of the predictions for the Lick Observatory :—

	Disappearance.	Reappearance.
Computed . .	$2^h\ 25^m{\cdot}4$	$4^h\ 38^m{\cdot}2$
Observed . .	2 23	4 37
By graph . .	2 25	4 37

* Interpolated from 10-day ephemeris in *Annuario Astronomico pel* 1918, pubblicato dal R. Observatorio di Pino Torinese.

♀ Interpolated from *Nautical Almanac* for 1918. Hourly motions are interpolated from *Connaissance des Temps*, 1918, and checked from *Nautical Almanac* for 1918.

† H. Thiele, "Observations connected with the Occultation of 7 Aquarii by Venus, 1918 March 2, G.M.T., at the Lick Observatory, Mount Hamilton." *Publ. Astr. Soc. Pacific*, 30 (No. 174), 1918 Apr., pp. 166–170.

§ 3. In explaining the method we shall confine ourselves to the case of an occultation of a star, as the method is most useful in providing a rapid means of forming a comprehensive picture of the whole occultation. The method could be applied also to solar eclipses, but is not sufficiently accurate for ultimate requirements.

As in Bessel's method of calculation the star and the occulting body, which we may call the moon, are projected orthogonally on the *fundamental plane*, the plane through the earth's centre O perpendicular to the line OS joining O to the star. The earth will be assumed to be spherical, and its intersection with the fundamental plane is the *primitive circle*. In this plane the axes of reference are taken, OY north and OX east.

With the notation of § 2, the latitude of the centre of the primitive circle is δ'. Its longitude at conjunction, or the longitude of the principal meridian, west of Greenwich, is

$$\lambda_0 = \mu_0 - \alpha \quad . \quad . \quad . \quad . \quad (1)$$

δ' is also, of course, the elevation of the pole, the north pole being elevated if δ' is positive or north declination.

The moon's centre is projected at M on the principal meridian. The radius of the primitive circle being unity, the co-ordinates of the point M are

$$x_0 = 0, \quad y_0 = (\delta - \delta')/p \quad . \quad . \quad . \quad . \quad (2)$$

The path of the centre of the shadow is assumed to be a straight line, and its gradient is determined by the velocity components

$$x' = \frac{\Delta\alpha}{p}\cos\delta, \quad y' = \frac{\Delta\delta}{p} \quad . \quad . \quad . \quad (3)$$

§ 4. We suppose now that a series of orthogonal projections has been prepared for polar elevations from 0° to, say, 30°, at 1° intervals. The radius of the circle, which is taken as unity, should be 10 inches, graduated in tenths of an inch, so that it is possible to read to ·001 of the radius. It is sufficient to have the parallels of latitude drawn at intervals of 10°, and the meridians at intervals of 1^h from the central meridian. The latitude and hour-angle should, however, be marked accurately on the margin of the primitive circle, for the purpose of drawing the chart.

Choosing the projection for the nearest polar elevation corresponding to δ', we draw the line representing the path of the shadow and graduate it in 5-minute intervals from the epoch of conjunction.

Fig. 1 represents the diagram for the occultation by Venus already referred to.

This diagram is now ready to be used for predicting the times of beginning and ending at any station and for constructing the chart.

§ 5. *To predict the Times of beginning and ending at any Station.*—Draw the parallel of latitude for the station and plot the position of the station at the hours measured from the epoch

of conjunction. Then, with the dividers set to the radius of the shadow, $l = r/p$, slide one end along the path of the shadow and the other along the parallel of latitude until the same times are indicated on both lines. Even without a fine graduation of the parallel of latitude these times are in many cases capable of fairly accurate determination by taking always the reading on the shadow-path, as a small movement along this line generally pro-

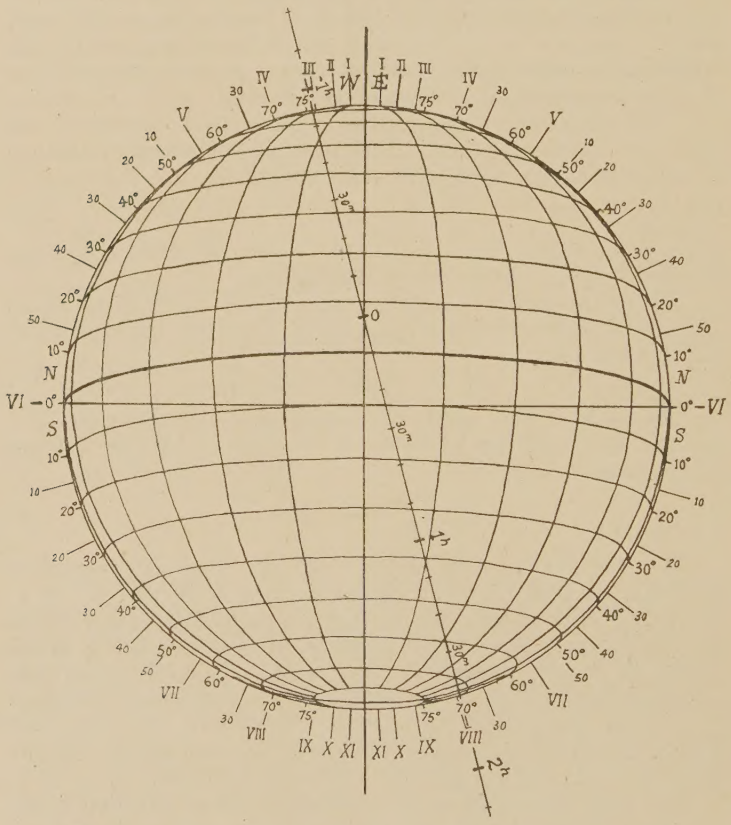


FIG. 1.—Occultation of 7 Aquarii by Venus. Projection on the fundamental plane.

duces a very much larger corresponding movement along the parallel of latitude. Determination of the times to the nearest minute is frequently possible.

§ 6. Further useful information about the occultation may be obtained by using a circular disk of paper with the radius of the shadow. On this disk mark a diameter to represent the path of the centre; it will be convenient to cut a slit along this line extending from the centre for several inches, so that the gradua-

tions of the path may be read through it. The disk should also have the north and south points marked on the edge, and, if it represents the moon or Venus, the terminator should also be drawn, or at least the line of cusps. This is easily constructed, since it is perpendicular to the line joining O to the subsolar point, whose latitude is $\delta_{\odot}$., and longitude, west of the principal meridian, $\alpha - \alpha_{\odot}$. The terminator can then be drawn from information in the *Nautical Almanac* relating to the phase of the moon or planet.

The appearance of the occultation as viewed from any station on the earth can now be represented on the fundamental plane. The circular disk moving with its centre along the path of the shadow represents the moon, and the star will be represented by the station itself. The motion of the station reproduces the apparent motion of the star due to parallax. The star will become occulted when the distance between the station and the centre of the shadow becomes equal to the radius of the shadow.

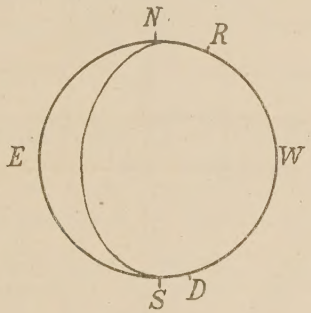


FIG. 2.

Placing the disk in position at the beginning or end of the occultation as viewed from the given station, the points of disappearance and reappearance can be marked on the edge and their position-angles measured. It is seen at a glance how these points are related to the bright limb.

Thus for the occultation of 7 Aquarii by Venus, fig. 2 represents the appearance at the Lick Observatory; the star disappeared at D and reappeared at R, in each case on the dark limb. The position-angles were found to be: for D 197°, for R 331°. It should be noticed, of course, that in order to get the true appearance as viewed from the earth's surface, the disk should be viewed from the under side.

In the case of an occultation of a star by the moon or a planet it will be useful also to draw the line of sunrise or sunset on the projection, as this will show whether the occultation will occur in daylight or not. The curve is a semi-ellipse whose major axis is perpendicular to the line OS which joins the centre of the primitive circle to the subsolar point. If SP is drawn perpendicular to OS cutting the primitive circle in P, the minor axis = SP.

The diagram for the occultation of 7 Aquarii by Venus showed that at Lick the disappearance would occur about a quarter of an hour before sunrise, the reappearance about two hours after sunrise.

§ 7. For an occultation in the case of a station which lies outside the limits of the shadow, the nearest approach may be found as follows:—At the instant of closest approach the apparent direction of motion of the shadow is perpendicular to the line joining the station to the simultaneous position of the centre of the shadow. As a first approximation take the shadow-path as the direction of motion of the shadow; slide a set-square with one edge on the shadow-path until the other passes through the position of the station at the same time. Then construct the line of the apparent direction of motion of the shadow by using the estimated velocity of the station at that instant, and repeat the process. The time indicated will give the time of closest approach, and the distance d can be measured between the station and the centre of the shadow. The distance of closest approach is then $(d-l)p$, since the radius of the primitive circle represents p in angular measure.

§ 8. *Construction of the Chart.*—The curves required for the chart are—

(1) The path of the centre of the shadow.
(2) The line of simple contact.
(3) The rising and setting curve.
(4) The curve of maximum in the horizon.

These may all be obtained easily and quickly from the diagram, with sufficient accuracy for the purpose of drawing the chart. The chart for the occultation of 7 Aquarii by Venus is given in fig. 3.

(1) *The Path of the Centre.*—Determine for a sufficient number of points on the path the latitude, and hour-angle h, measured west from the principal meridian. Tabulate these values together with the time t measured from the epoch of conjunction. The longitude λ of the corresponding point on the chart is then

$$\lambda = \lambda_0 + h + t \quad . \quad . \quad . \quad . \quad (4)$$

measured, in time, west of Greenwich. In the case of an occultation t should be reduced to sidereal time, but the difference is not perceptible. The latitude and hour-angle should be determined as carefully as possible for the ends of the path, where it leaves the earth; for the other points it will be most convenient to take those which lie on exact meridians, as the latitudes are more easily estimated than the hour-angles.

(2) The *lines of simple contact* are the loci of points from which the star will just appear to graze the moon. Two conditions must then be satisfied, viz. (i) the point in the fundamental plane must be at a distance equal to the radius of the shadow from the path of the centre, (ii) the apparent direction of motion of the shadow

must be perpendicular to the line joining the point to the simultaneous position of the centre of the shadow.

To find the apparent direction of motion of the shadow, we have to compound the velocity of the centre of the shadow with the reversed component of the velocity of the station parallel to the fundamental plane. The latter component is always much less than the velocity of the shadow. As a first approximation let us

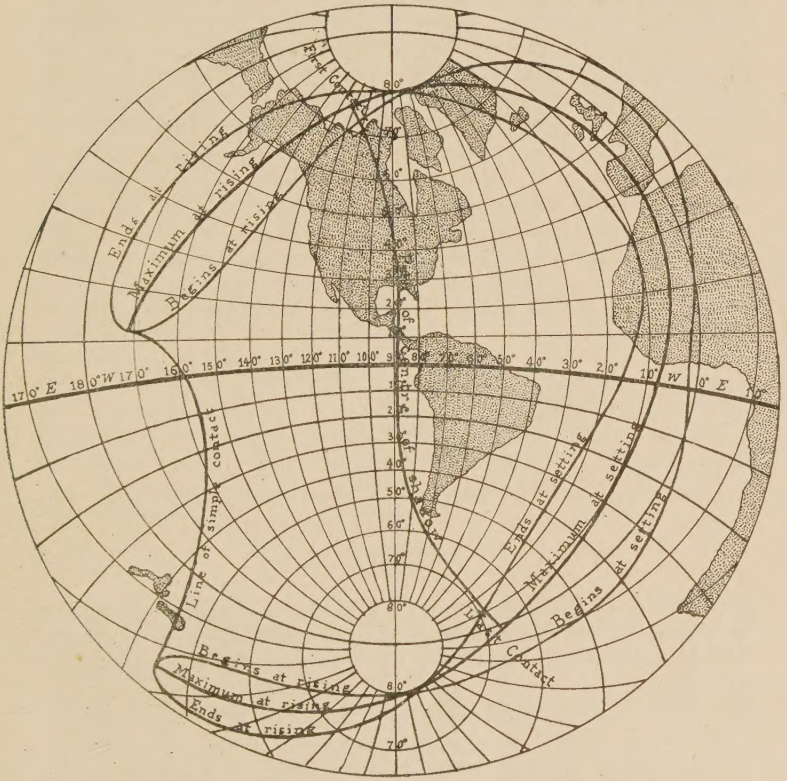


FIG. 3.—Chart of the occultation of 7 Aquarii by Venus, 1918 March 2. (Stereographic projection).

neglect this. We shall then have the following simple construction for the line of simple contact:—

Draw two lines (if possible) parallel to the path of the centre and at a distance from it equal to the radius of the shadow. For each point on these lines tabulate the latitude and hour-angle, and the time from conjunction indicated by the foot of the perpendicular on the path of the centre. Then find the longitudes by (4) and transfer to the chart. The two lines, when they exist, are the northern and southern lines of simple contact.

In general, however, this will scarcely be a close enough approximation for a curve which determines the limits of visibility of the occultation, and we must consider more carefully what effect will be produced by taking into account the motion of the station.

Let AB (fig. 4) represent the path of the centre, n its velocity or hourly motion, which we shall assume is from west to east. Let CD be the southern parallel, S the station, and SN perpendicular to AB. The velocity of S is in the direction ST, tangent to the parallel of latitude through S, and equal to v. Compounding n and v reversed, let A′B′ be the direction of the resultant, which is the apparent direction of motion of the shadow as viewed from S. Draw SN′ perpendicular to A′B′ meeting AB in N′. Let ϕ and h be the latitude and hour-angle (west of the principal meridian)

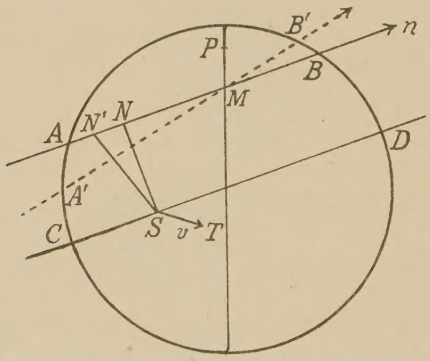


FIG. 4.

of S. Then in the first approximation the corresponding point S′ on the chart will have latitude ϕ and west longitude $\lambda_0 + h - t$, where t is the time measured by NM previous to conjunction. As a second approximation we shall correct the longitude by subtracting the time corresponding to NN′. The effect is to move S′ to S″ along a parallel of latitude to the east.

In the first approximation S is actually on the edge of the shadow, but as the apparent direction of motion is not tangential to the shadow the occultation is beginning or ending, and S′ is certainly within the extreme limits. The second approximation is practically equivalent to assuming for the point S the radius of the shadow equal to N′S which is greater than NS, hence S″ will be outside the extreme limits. The true line of simple contact will lie between these two approximations.

(3) *The Rising and Setting Curve.*—This is the locus of points at which the occultation is beginning or ending when the star is on the horizon. We take then a number of points on the circumference of the primitive circle. From each point span the dividers, set to the radius of the shadow, to the path of the shadow

and tabulate the latitude, hour-angle, and time. Hence find the longitudes by (4) and transfer to the chart.

(4) *The Curve of Maximum in the Horizon.*—This is the locus of points at which the middle or maximum of the occultation occurs when the star is on the horizon. At such points the apparent direction of motion of the centre of the shadow is at right angles to the line joining it to the star, and therefore in the fundamental plane the line joining the station to the simultaneous position of the centre of the shadow must be perpendicular to the apparent direction of motion of the shadow.

A fairly good approximation may be obtained by neglecting the motion of the station. With this simplification the construction for points on the maximum curve will be as follows:—

Slide a set-square with one side on the path of the shadow; read the time there, and the latitude and hour-angle of the point where the perpendicular edge cuts the margin of the primitive circle. Then obtain the longitudes by (4) and transfer to the chart. A curve will be obtained which makes a complete circuit, but in general part of this will lie outside the lines of simple contact. These parts of the curve, which consist of the points at which the nearest approach occurs on the horizon, no occultation taking place, are to be rejected.

§ 9. In drawing the chart, as rapidity is the chief advantage of the approximate method described in this paper, it would be advisable to have blank charts, with outlines of the continents, already prepared. These might be on Mercator's projection, or any convenient projection capable of showing the whole of the earth's surface.

On the form of an Eclipse Chart near the Pole. By Professor D. M. Y. Sommerville, Victoria Univ. Coll., Wellington, N.Z.

(*Communicated by the Secretaries.*)

§ 1. Buchanan* pointed out that when the rising and setting curve is of the distorted figure-of-eight type the curve of maximum in the horizon does not in general pass through the node, although it appears to be so depicted on all the *Nautical Almanac* charts before 1903.†

It is the object of this paper to explain geometrically the con-

* Roberdeau Buchanan, *The Mathematical Theory of Eclipses* (Philadelphia, 1904), p. 80.

† In the chart of the annular eclipse of 1903 March 28, and again in that of the total eclipse of 1905 Aug. 29–30, the maximum curve is drawn on the wrong side of the node. The only case in which the maximum curve can pass through the node is when the pole is on the primitive circle, in which case the node is at the pole. This happened very nearly in the total eclipse of 1903 Sept. 20, but in the *Nautical Almanac* chart there appears quite a large triangular region.

ditions for the existence of a node, and to describe the physical meaning of the triangular region formed on the earth's surface.

§ 2. We shall simplify matters by confining our attention to the case of an occultation of a star, so that we can assume that the fundamental plane is fixed and the diameter of the shadow is constant; we shall also neglect the compression of the earth, and assume that it is a perfect sphere. The results will be very similar to those for a solar eclipse, although the actual details will require modification, especially near the critical points.

§ 3. Let AB (fig. 1) represent the path of the centre of the shadow going with velocity n in a direction making an acute*

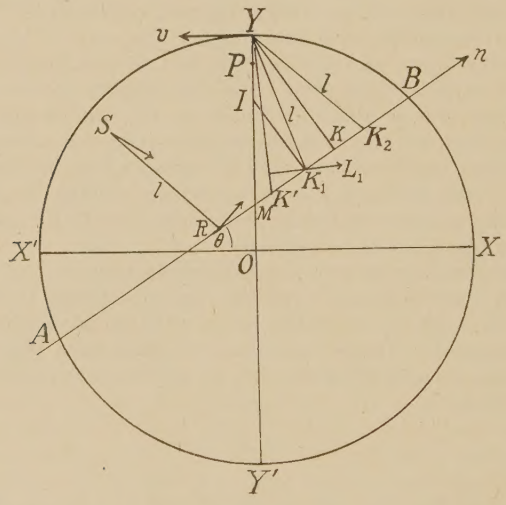


FIG. 1.

angle θ with OX, and cutting the principal meridian at M. Y and Y′ are the north and south points on the primitive circle, and P is the elevated pole. If δ is the declination of the star, the primitive circle touches the two parallels of N. and S. latitude $90° - \delta$.

§ 4. The rising and setting curve is constructed as follows:— Let T be any point on the primitive circle, draw a circle with centre T and radius equal to l, the radius of the shadow, cutting AB in K_1 and K_2. When the centre of the shadow reaches K_1 or K_2 the occultation is beginning or ending when the star is on the horizon, *i.e.* either rising or setting. If T is to the left of YY′ the star is rising, if to the right it is setting. To determine whether it is beginning or ending at K_1, determine the apparent direction K_1L_1 of the shadow as viewed from T by compounding with its actual velocity n the velocity of T reversed. Then the occultation

* This will always be the case except in rare cases of occultations by planets in the retrograde part of their path, and transits of Venus.

is beginning or ending according as the angle TK_1L_1 is acute or obtuse.

Then, to find the corresponding points on the chart, let ϕ be the latitude of T, h its hour-angle west from the principal meridian, t_1 and t_2 the times at which the centre of the shadow reaches K_1 and K_2 after the time of conjunction. Then the latitude of each of the points Y_1 and Y_2 on the chart is ϕ, and their longitudes west of the principal meridian are $h+t_1$ and $h+t_2$.

To construct the maximum curve, draw TK′ perpendicular to the apparent direction of the shadow, meeting AB in K′, and transfer to the chart as before.

Lastly, the line of simple contact is constructed by taking points S such that, when SR is drawn perpendicular to the apparent direction of the shadow meeting AB in R, $SR=l$.

§ 5. Let us consider now the conditions in order that a node should be formed on the rising and setting curve.

Suppose first that the shadow passes entirely between Y and Y′, so that if CD and C′D′ are the two lines parallel to AB at distance l, C and C′ are both to the west and D and D′ both to the east of YY′. Then the rising and setting curve consists of two separate closed curves, one for rising and the other for setting. Neither of these can have a node, and unless n is much smaller than usually happens the two curves will not cut one another.

Secondly, suppose the shadow passes entirely outside the segment YY′. Then, unless the radius of the shadow is less than $\frac{1}{4}$ that of the primitive circle—in other words, unless the occulting body is certainly smaller than the moon,—one of the lines CD or C′D′ fails to cut the primitive circle, and the rising and setting curve consists of only one closed curve which cannot have a node.

A *necessary* condition for a node therefore is that the shadow should pass over the north or south point on the primitive circle.

§ 6. We shall now consider the case in which the shadow passes over the north or south point on the primitive circle, say the north point Y, so that the perpendicular $YK<l$. Draw a circle (fig. 1) with centre Y and radius l cutting AB in K_1 and K_2, and draw YK′ perpendicular to the apparent direction of the shadow at Y meeting AB in K′. Then there are two points Y_1 and Y_2 on the rising and setting curve, and one point Y′ on the maximum curve, corresponding to Y. Since Y is the point on the primitive circle which is nearest to the pole, with polar distance δ, *the rising and setting curve and the maximum curve both touch the parallel of latitude* $90^\circ-\delta$ *at the points* Y_1, Y_2, and Y' *respectively.* We shall suppose that the pole P is elevated so that the velocity of Y is to the left, and K′ lies between M and K.

§ 7. To trace the curves in the neighbourhood of the point Y, we must give Y a small displacement along the primitive circle. If Y moves towards B, K_2 will also be displaced towards B, hence we get a point on the "curve of setting when ending" slightly to the west of Y_2; and similarly we get a point on the "curve of rising when ending" slightly to the east of Y_2. To

determine the direction of motion of K_1, consider YK_1 as a line of fixed length with its ends sliding on YB and MB. The instantaneous centre for this motion is at I on MY where $IK_1 \perp AB$. Hence Y and K_1 move in opposite directions from B. To determine whether the actual displacement of Y_1 is to the east or the west, we must consider the magnitudes of the displacements. Let the small displacements of Y and K_1 in the directions of v and n be v' and n'. Then

$$\frac{v'}{n'} = \frac{IY}{IK_1} = \frac{K_1K}{MK_1 \cos\theta}.$$

Now by the displacement v' the point Y_1 is moved to the east through longitude v'/v hours, and the displacement n' of K_1 has the effect of moving Y_1 to the west through longitude n'/n hours. Hence the total displacement of Y_1 in longitude west is

$$\frac{n'}{n} - \frac{v'}{v} = \frac{n'}{n}\left(1 - \frac{n}{v}\frac{K_1K}{MK_1 \cos\theta}\right).$$

Now, since YM, YK, and YK′ are perpendicular respectively to the directions of the velocities v, n, and their resultant,

$$\frac{n}{v} = \frac{\sin MYK'}{\sin KYK'} = \frac{MK' \cos\theta}{K'K}.$$

Hence

$$\frac{n'}{n} - \frac{v'}{v} = \frac{n'}{n}\left(1 - \frac{MK'}{K'K} \cdot \frac{K_1K}{MK_1}\right).$$

§ 8. Consider first the case in which K′ lies between K_1 and K, then $n'/n - v'/v$ is negative. At the point Y_1 the occultation is beginning on the horizon, and we get a point on the "curve of beginning when rising" slightly to the east of Y_1, and a point on the "curve of beginning when setting" slightly to the west of Y_1. The curves "beginning when setting" and "ending when rising" meet at a point U, so that a node is formed on the rising and setting curve. The chart is thus of the form indicated in fig. 2.

Fig. 3 represents similarly the case in which the north pole is depressed. The diagrams for the south pole may be found by turning these upside down and interchanging the words "begins" and "ends," "rising" and "setting." Also, if the shadow goes from east to west, the corresponding diagrams may be obtained by interchanging the words "begins" and "ends."

§ 9. What is then the physical meaning of the triangular region UVW? Taking fig. 2, in which the north pole is elevated, within the triangle the star is nearly circumpolar and only dips slightly below the horizon. What happens then is this. The occultation begins before the star sets, the maximum phase occurs while it is below the horizon, and it ends after the star has again risen. In fig. 3, where the pole is depressed, the beginning and end of the occultation in the triangular region occur when the star is below the horizon, the maximum phase taking place above the horizon.

§ 10. Consider now the case in which K′ lies outside K_1K_2, *i.e.* in fig. 1 between M and K_1. Then $n'/n - v'/v$ is positive. At both points Y_1 and Y_2 the occultation is ending on the horizon, and we get a point on the curve "ending when rising" slightly to the west of Y_1, and a point on the curve "ending when setting"

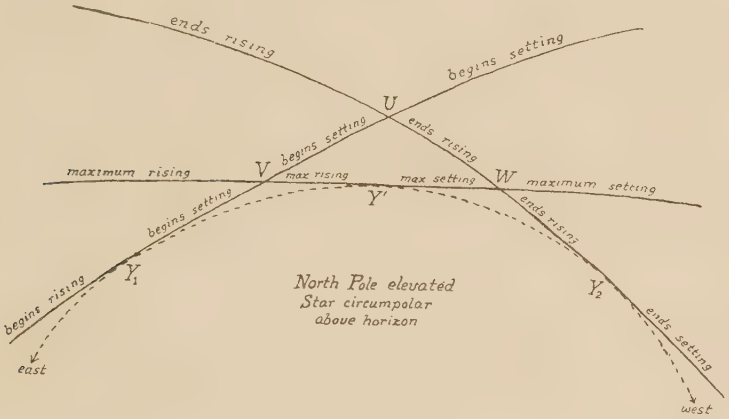


FIG. 2.

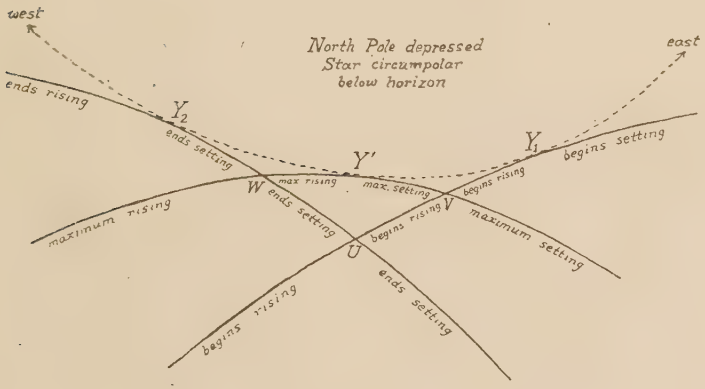


FIG 3.

slightly to the east of Y_1. There is then no node, and the chart is of the form indicated in fig. 4. Since $l = YK_1 < YM < CN$, there is in this case a northern limit of simple contact.

§ 11. In order that there should be a node on the rising and setting curve it is therefore necessary, but not sufficient, that the shadow should pass over the north or south point on the primitive

circle. The further condition is necessary that the segment K_1K_2 should contain the point K′, *i.e.* that

$$\frac{n}{v} < \frac{MK_1 \cos\theta}{K_1K},$$

i.e.

$$\frac{n}{v} < \frac{\sin\theta\cos\theta}{\{l^2/(l-y_0)^2 - \cos^2\theta\}^{\frac{1}{2}}} - \cos\theta.$$

θ, l, y_0 and n can all be calculated from the elements, and $v = \frac{\pi}{12}\sin\delta$.

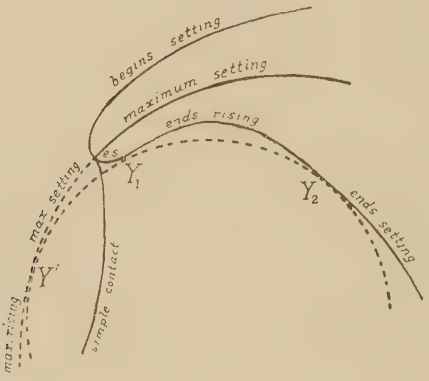


FIG. 4.

In the limiting case, when there is an equality, the rising and setting curve has a cusp, and the chart is of the form in fig. 5.

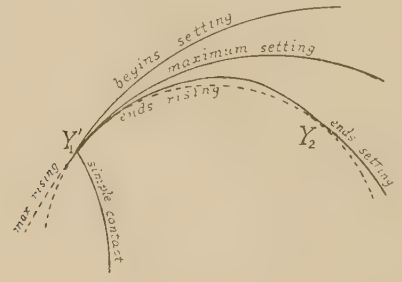


FIG. 5.

Note on Apparent Changes in the Spectrum of η Carinæ.

By F. E. Baxandall, A.R.C.Sc.

(*Communicated by the Director, Solar Physics Observatory.*)

Records of the spectrum of this star have been published by Miss Cannon,* Sir David Gill,† and Moore and Sanford.‡ The first partakes more of the nature of a general description of the spectrum rather than a detailed analysis. In the two latter, detailed lists of lines are given, and in each case a reproduction of the spectrum is added, Gill's plate showing both a slit spectrum and an objective prism spectrum, and Moore and Sanford's a slit spectrum only. In each case the slit spectrum has a comparison spectrum of iron, so that the two spectra, taken at an interval of thirteen years, are readily comparable. Miss Cannon describes the spectrum of η Carinæ as consisting of both dark and bright lines or bands, the dark-line spectrum being of class F5 and the bright lines or bands being similar to those of Nova Aurigæ. The spectra were described as varying considerably on different plates. Miss Cannon says: "On the best plates the system of dark lines is well defined and the bright bands are not numerous. On some plates the dark lines appear inconspicuous, and nearly the whole spectrum is crossed by bright lines. On other plates dark lines are distinctly seen on the edges of shorter wave-length of the bright bands."

Although the Harvard analysis was prior to Gill's, that observer does not refer to the Harvard results, and it would appear that, as the Harvard volume was not published until 1901, the same year as Gill investigated his spectra, he had not had access to Miss Cannon's description of the spectrum. This point is mentioned here because Gill makes no reference whatever to the spectrum containing dark lines, and treats it as purely a bright-line spectrum. As Moore and Sanford, in their more recent paper, also refer to the spectrum of η Carinæ as "essentially a bright-line" one—and their reproduced spectrum apparently shows only bright lines, with no dark lines or continuous spectrum,—three alternatives seem to present themselves. Either (1) the spectrum had undergone a change between the dates of the Harvard and Gill's spectra—apparently an interval of some five years: or (2) the Harvard observers had, in some way or other, misinterpreted some of the intervals between bright lines as dark lines, and measured them as such; or (3)§ the exposures used by Gill and Moore and Sanford had been such as to fail to record the dark lines and continuous spectrum obtained by the Harvard observers. That the second alternative is the most likely

* *Ann. Harv. Coll. Ob.*, **28**, 175, part ii., 1897.

† *Monthly Notices R.A.S.*, **61**, Appendix, p. 66, 1901.

‡ *Lick Obs. Bull.*, **8**, 55, 1913.

§ This alternative was added after the return of my note from the Cape Observatory.—F. E. B.

one is suggested, though by no means proved, by the fact that in the interval between Gill's and Moore and Sanford's investigations the spectrum has not altered, in so far as it seems to be, at both epochs, a bright-line spectrum.

Although, however, Gill's spectra of 1901 and Moore and Sanford's of 1913 show only bright lines, a comparison of their reproduced spectra appears to show a few changes in the relative intensity of some of the lines common to the two spectra. These may be now referred to in detail.

Lines { λ M. and S. 4233·30 pFe. 4244·25 Unknown. Gill's spectrum (objective prism) shows these two as equally strong. His tabular intensities are 7, 7. Gill's spectrum (with slit) shows the two components of the pair as being nearly equal in intensity. His tabular intensities are 5, 7. Moore and Sanford's spectrum shows 4244·25 as much the stronger line. Their tabular intensities are 5, 8.

Lines { λ M. and S. 4372·72 Unknown. 4385·49 pFe. 4394·84 Unknown. Although these are all given in Moore and Sanford's tables, only the first two are detectable in the reproduction, 4385·49 being much the stronger line. Their tabular intensities are 0, 2, 0. Gill, however, only records the third (4395·8) in his tables, and gives intensity 3.

In the objective-prism spectrum shown in fig. 2 of his plate, all three lines are distinctly shown, and if we adopt his estimated intensity (3) for the 4395·8 line (M. and S.'s λ is 4394·84), the intensities of the others would be { 4373 line, Int. 1. 4385 line, Int. 2½.

Thus, as a comparison of intensities from the two records, tabular and photographic, we have:—

λ M. and S.	Intensity. M. and S.'s Tables.	M. and S.'s Plate.	Gill's Tables.	Gill's plate. (Fig. 2).
4372·72	0	0	...	1
4385·49	2	2	...	2½
4394·84	0	Not visible	3	3

The reproductions are in each case direct enlargements from the original spectra, and there appears to be no reason to doubt the reality of the differences shown. In Gill's plate, 4395 is certainly the strongest line of the three; in Moore and Sanford's, 4385·49 is quite the outstanding line of the three.

Lines { λ Gill. 4665 Unknown. 4811·6 Unknown. In Gill's plate (fig. 2) 4665 is a little stronger than 4811·6. The intensities for these in his table are

$\begin{cases} 3 \\ 1 \end{cases}$. In Moore and Sanford's reproduction 4814·78 (M. and S.'s λ) is quite an outstanding line, whereas there is only the merest trace of a line in the region of 4665.

There may be other differences in the two published spectra, but as the bright bands are mostly crowded together, and in Gill's spectrum are more or less diffuse, it is difficult to detect genuine changes. Enough has been pointed out, however, to show what an interesting spectrum it is, and more light would probably be shown on the variations if other spectra of the star could be taken with fairly high dispersion at intervals of a few years, to compare with the admirable spectrum published by Moore and Sanford. The spectrum is of a type almost unique, in that it represents a reversal of most of the strongest enhanced lines of α Cygni (silicon and magnesium notably excepted), with the addition of several very conspicuous lines which have not yet been identified with lines of any terrestrial element.

On the Spectrum of η Argûs. By Joseph Lunt, D.Sc. (Plate 18.)

(*Communicated by S. S. Hough, M.A., F.R.S., H.M. Astronomer at the Cape.*)

In a MS. note * sent to the Cape Observatory, Baxandall calls attention to apparent changes in the spectrum of η Argûs which he noticed on comparing photographs of the spectrum taken at the Cape in 1899 † with others taken in 1913 ‡ at Santiago.

He calls attention to the variations noted by Miss Cannon § in the Arequipa photographs, and suggests that the spectrum should be examined with fairly high dispersion at intervals of a few years, as the type of spectrum is almost unique, and contains conspicuous lines which have not been identified with lines of any terrestrial element.

The photographs examined by Miss Cannon were taken between the end of 1891 and the end of 1899, therefore not much earlier than the Cape plates; they show much greater variation, according to Miss Cannon's description, than the later plates exhibit, particularly as regards the occurrence of dark lines, as the following quotations show:—"Taking only the dark lines into consideration, the spectrum would be classed F5G. Considering only the bright lines, there is a marked resemblance to the spectrum of Nova Aurigæ as photographed on 1892 February 17."

"Different aspects appear on different plates. On the best plates the system of dark lines is well defined, and the bright

* Now published, p. 619, *supra*.
† *M.N.*, 61, Appendix (66). ‡ *Lick Observatory Bulletins*, 8, 55, 134.
§ *Harvard Annals*, 28, 175. (For later notes see *H.A.*, 76, 36–37.)

bands are not numerous. On some plates the dark lines appear inconspicuous, and nearly the whole spectrum is crossed by bright bands. On other plates, dark lines are distinctly seen on the edges of shorter wave-length of the bright bands."

Two photographs were therefore taken here on the dates following:—

1919.	Sid. Time Mid. Exp. h m	Expr. h m	Observer.*	Corrn. ⊙. km./sec.	
Feb. 20	8 29	3 0	JL	+12·1	Plate 5423. Total exposure $9^h\ 0^m$.
21	8 38	3 0	RW	+11·9	
22	8 15	3 0	AB	+11·8	
Apr. 14	9 36	2 50	AB	−0·4	Plate 5446. Total exposure $8^h\ 50^m$.
16	9 28	3 0	RW	−0·9	
17	9 23	3 0	JL	−1·2	

The two Santiago plates taken in 1913 received exposures on one night only of 5 h. 45 m. and 5 h. 32 m. respectively, and the spectra are not so strong as those on the Cape plates, which were taken with the four-prism slit spectrograph and short camera, giving a scale double that of the Santiago photographs. Comparison with Moore and Sanford's published photograph shows that the 1919 spectra are almost identical with the 1913 photographs, and the radial velocity of the star, as determined from the shifts of the enhanced iron lines, agrees well with Moore and Sanford's value.

The spectra consist principally of diffuse bright lines, often with a sharper and narrower brighter region, not always centrally placed, with a background of more or less marked continuous spectrum crossed by dark lines, which appear in some cases to be real absorption lines; but they could not be identified with known lines, and they may be merely interspaces between the bright lines.

The spectrum on Plate 5446 is sent for reproduction.

All the final wave-lengths of the lines are affected by the uncertainty of the correction for shift.

The internal agreement of the shifts of the iron lines is not all that could be desired, and it is possible that some of the lines are blends with unknown lines, as the two plates agree well with each other. For example, Lockyer's enhanced iron line 4451·75, ascribed by Rowland to manganese in the sun, is—in η Argûs—distinctly to the red of the tabular position: the wave-lengths, corrected for shift, are 4452·25 (Lunt) and 4452·11 (Moore and Sanford). It is the most discordant line in both 1919 plates, and has not been used for the velocity determination by Moore and Sanford. Reese excludes it as an enhanced iron line. It is absent from the enhanced lines measured in the dark-line spectrum of Nova Aquilæ, but in η Argûs it is a strong line. Another example is Lockyer's enhanced iron line 4556·09. Rowland gives 4556·06, and no origin in the sun. In η Argûs the line is dis-

* JL = Lunt. RW = Woodgate. AB = Baines.

placed to the violet, 4555·72 (Lunt) and 4555·86 (Moore and Sanford). It has the highest shift to the violet in both 1919 plates, and also in the 1913 plates. It is almost certainly blended with the enhanced chromium line 4555·16.

Table I. gives the measured displacements in km./s. for both plates, those of the second plate being, for comparison, reduced to the date of the first plate by adding the difference in the sun corrections between the two dates.

Table II. shows the wave-lengths of the lines measured, corrected for mean shifts determined as in Table I., viz. −42·6 for plate 5423 and −27·4 for plate 5446.

The measures are from single settings, except in the region to the red side of the iron line 4737, where four settings were made on each line.

The wave-lengths were corrected by frequent reference to the iron spark lines. The spectrum of the iron spark was impressed on the plates by exposures of five seconds at the beginning and end of each exposure of three hours.

Baxandall calls particular attention to the relative intensities of the components of the pairs of lines 4233, 4244 and 4665, 4811 and to the group of three lines 4374, 4385, 4395.

It is questionable whether photographs taken with an object-glass prism are strictly comparable as regards relative intensities of lines with photographs taken with a slit spectrograph, as in the former case certain lines peculiar to a substance existing as an extensive stellar envelope may be broader, and therefore appear brighter, than the same lines narrowed down by a slit.

The components of the first pair of lines 4233, 4244, have the same relative intensity in 1919 as in 1913, and agree fairly well with those in 1899 taken with the slit spectrograph, but with the object-glass prism (1899) 4233 is relatively stronger.

In the case of the pair 4665, 4811, the latter line appears to have become stronger than in 1899 both in 1913 and 1919, particularly when the slit photographs are compared.

In the group of three lines above mentioned only the least refrangible was measured by Gill and it was then the strongest, whereas it is now the weakest line of the group, as the following intensities show:—

1919 (JL).	Intensity.	1913 (M and S).	Intensity.	1899 (DG).	Intensity.
4372·57	1	4372·72	0		
4385·87	1·5	4385·49	2		
4394·63	0	4394·84	0	4395·8	3

Of much greater interest, however, than the slight variations of intensity of individual lines is the question of their chemical origin.

Moore and Sanford give a long list of chromospheric lines fitting the η Argûs lines more or less closely, with which identifications are suggested.

TABLE I.

η Argûs. Enhanced Iron Lines.

	λ Lockyer.	R's ⊙.	Intensity. Lockyer.	η Argûs. Shift in km./s. 5423	5446.†	η Argûs. Mean λ. (Corrected.)	Intensity.	Δ η − R.	η Argûs. λ M and S.	Intensity.
	4173·61	·48	3	−38	−43	4173·49	0	+·01	73·66	1
	79·05	·03	3–4	(Blend		78·23)	1	...	78·23	0, 1
	4233·32	·33	4–5	53§	51§	4233·19	5	−·14	33·20	5
	96·72	·74	2	36	36	96·82	0	+·08	96·87	0
	4302·35	...	2–3							
	03·34	·34	4	29	37	4303·46	1	+·12	03·23	1
	51·93	·93	5	26	14	52·25	7	+·32	52·26	8
	85·55	·55	3–4	51	62	85·87	1·5	+·32	85·49	2
	4451·75	·75	3	13	4	4452·25	4	+·50	52·11	6
	62·30	·37	2							
Mean	89·35	·35	1				4			3
	90·46	·46	...	55	45	m 90·48	...	+·02	90·48	...
	91·57	·57	2	...	...	d 90·34	5	−·12		3
	4508·46	·46	5	53	37	4508·41	5	−·05	08·55	5
	15·51	·51	4	59	60	15·24	5	−·27	15·45	5
Mean	20·40	·40	3				4			3
	21·59	·60	...	58	61	m 21·46	...	−·14	21·60	...
	22·77	·80	6	...	...	d 21·33	6	−·27		5
	41·46	·69	3	37	37	41·75	1	+·06	41·78	0
	49·64	·64	7	40	41	49·66	7	+·02	49·50	7
	56·09	·06	5	62‡	66‡	55·72	6	−·34	55·86	4
	76·51	·51	1	56	22	76·55	2	+·04	76·74	2
	84·02	·02	8	31	37	84·14	9	+·12	84·01	9
	4629·51	·52	4	27	34	4629·70	7	+·18	29·48	8
	35·50	·49	3	(Fe_ECr_E	Blend)					
	4924·11	·11	8	...	...	4924·11	5	·00	24·13	8
	5018·63	·63	7	...	...	5019·03	0*	+·40	18·78	5
	5169·07	·07	6							
	69·22	·22								
				Mean shift		−42·6	40·1 (= −27·4 − 12·7)			
				⊙ Corrn.		+11·9	11·9			
				Rad. Vel.		−30·7	28·2			
				Mean ,,	(1919)	−29·4				
				M and S ,,	(1913)	−27·7	Sanford (1914) −25·9, 2 Plates.			

* Near end of spectrum. Not full beam.
m = mean of measures of two bright lines.
d = measure of dark space between two bright lines (or absorption line ?).
† Added −12·7 (Diff. of ⊙ Corrns. +11·9 and −0·8) to bring shifts to same date.
‡ P.S. Blended with enhanced chromium line 4555·16.
§ Possibly involved with enhanced chromium line 4233·50.

TABLE II.

The Spectrum of η Argûs.

Plate 5423.	Plate 5446.	Mean λ 1919 (1).	Intensity.	Moore and Sanford, 1913. λ (2).	Moore and Sanford, 1913. Intensity.	Difference in λ (2)−(1).	Origin.	Rowland's λ.	Remarks.
4068·90	68·51	68·71	00						
Hδ	...	...	0	Hδ					
4123·02	diff.	23·02	000						
43·23	43·06	43·15	000	...	...	...	...	...	Narrow bright.
71·81	diff.	71·81	000						
72·45	72·29	72·37	d	...	...	...	...	...	Narrow dark.
73·54	73·44	73·49	0	73·66	1	+·17	Fe_E	4173·48	
78·20	78·26	78·23	1	77·55	0	·00	...	...	Broad.
				78·91	1		Fe_E	4179·03	Possibly duplex.
v.f.	01·07	01·07	00						
4233·18	33·19	33·19	5	33·30	5	+·11	Fe_E	4233·33	
43·88	43·97	43·93	8	44·25	8	+·32	...	...	Diffuse to red.
...	...	...	...	45·51	1	...	...	...	No distinct line.
58·69	58·10	58·40	00						
...	...	...	...	73·78	0				
76·90	76·88	76·89	4	77·01	5	+·12	..	..	Diffuse to violet.
87·43	87·48	87·46	9	87·45	10	−·01	...	...	Diffuse to red.

d = dark line or space.

TABLE II.—*continued.*

Plate 5423.	Plate 5446.	Mean λ 1919 (1).	Intensity.	Moore and Sanford, 1913. λ (2).	Moore and Sanford, 1913. Intensity.	Difference in λ (2)−(1).	Origin.	Rowland's λ.	Remarks.
...	...	...	...	89·88	2	...	...	...	No definite line.
...	95·44	95·44	d						
4296·83	96·80	96·82	0	96·87	0	+·05	Fe_E	4296·74	
98·28	98·39	98·34	d						
4303·54	03·39	03·46	1	99·78 03·23 05·92	0 1 1	−·23	Fe_E	4303·34	Line on continuous background.
diff.	04·50	04·50	d	...	...	...	...	...	Followed by shading.
...	08·27	08·27	...	...	...	...	...	...	Shading ends.
13·49	13·32	13·41	00						
...	16·70	16·70	d						
19·78	19·92	19·85	2	19·70	2	−·15	...	...	Unknown in α Cygni.
...	...	...	...	24·64	0	...	...	...	Faint continuous background.
...	...	...	...	26·88	0	...	...	...	
...	30·42	30·42	00	30·19	0	−·23	...	...	Rather indefinite, 1 Plate.
36·95	37·29	37·12	1	...	...	...	...	...	? Part of H_γ.
38·05	38·50	38·28	d						
(H_γ	Table V.)		3 6	40·54 42·74	5 4	...	H_γ		

47·10	46·71	46·91	1	46·77	1	−·14	...	...	? Part of H_γ.
52·17	52·32	52·25	7	52·26	8	+·01	Fe_E	4351·93	(Cr int. 10 at 51·97 E and H).
59·34	59·50	59·42	10	59·11	10	−·31			
62·66	62·08	62·37	2	61·51	2	−·86	...	..	Ill-defined.
...	65·19	65·19	...	...	...	...	...	...	Band ends.
...	69·59	69·59	000	...	...	...	...	...	Narrow faint line.
72·55	72·59	72·57	1	72·72	0	+·15			
82·78	82·23 (?)	82·50	0						
84·09	83·68	83·89	d						
85·42	86·32	85·87	1·5	85·49	2	−·38	Fe_E	4385·55	
94·72	94·54	94·63	0	94·84	0	+·21			
...	97·39	97·39	d						
...	99·22	99·22	00						
4403·50	...	03·50	d	...	...	...	...	...	f. dark line?
04·02	...	04·02	000	...	...	...	...	...	f. bright line?
...	11·21	11·21	000						
13·84	13·92	13·88	8	14·04	8	+·16	...	...	Unknown in α Cygni 4413·5.
15·17	15·11	15·14	d						
16·59	16·68	16·64	9	16·43	9	−·21	...	...	Diffuse to red.
...	17·95	17·95	d						
...	19·27	19·27	0	...	...	...	...	...	f. Unknown line in α Cygni.
21·52 (!)	...	21·52	000						

d = dark line or space.

TABLE II.—*continued.*

Plate 5423.	Plate 5446.	Mean λ 1919 (1).	Intensity.	Moore and Sanford, 1913. λ (2).	Moore and Sanford, 1913. Intensity.	Difference in λ (2)−(1).	Origin.	Rowland's λ.	Remarks.
...	26·75	26·75	000						
4443·41	43·11	43·26	0	42·99	0	− ·27			
48·21 (?)	...	48·21 (?)	000						
52·19	52·30	52·25	4	52·11	6	− ·14	Fe_E	4451·75	
...	...	...	...	55·10	0	...	...	...	No definite line.
58·08	58·22	58·15	3	57·97	5	− ·18			
61·27	60·96	61·12	00						
68·23	68·51	68·37	00	68·10	0	− ·27			
74·57	75·25	74·91	2	74·87	3	− ·04			
88·92	89·02	88·97	4	89·21	3	+ ·24	Fe_E	4489·35	
90·28	90·39	90·34	d	...	...	...	...	90·46	
91·79	92·18	91·99	5	91·75	3	− ·24	Fe_E	91·57	
4500·69	00·71	00·70	0	00·60	0	− ·10			
08·30	08·51	08·41	5	08·55	5	+ ·14	Fe_E	4508·46	
15·26	15·21	15·24	5	15·45	5	+ ·21	Fe_E	15·51	
20·03	20·23	20·13	4	20·48	3	+ ·35	Fe_E	20·40	
21·36	21·29	21·33	d	...	...	...	...	21·60	
22·83	22·73	22·78	6	22·71	5	− ·07	Fe_E	22·80	
33·93	33·95	33·94	2	33·87	2	− ·07			

41·77	41·73	41·75	1	41·78	0	+·03	Fe_E	41·69	
49·68	49·64	49·66	7	49·50	7	−·16	Fe_E	49·64	
55·77	55·67	55·72	6	55·86	4	+·14	Fe_E, Cr_E	56·06 Fe_E.	4555·16 Cr_E.
59·58	59·35	59·47	3	58·56	2	−·91	Cr_E	58·83	
61·23	...	61·23	d						
63·55	63·51	63·53	1	63·59	1	+·06			
71·05	71·40	71·23	2	71·50	2	+·27			
76·30	76·79	76·55	2	76·74	2	+·19	Fe_E	76·51	
...	80·53	80·53	1	...	...	...	...	...	Unknown line in α Cygni 4580·3.
84·20	84·08	84·14	9	84·01	9	−·13	Fe_E	84·02	
88·19	87·87	88·03	3	88·20	3	+·17	Cr_E	88·38	Diffuse to red.
...	...	...	...	90·03	2	...	...	...	No definite line.
4616·74	...	16·74	000	16·59	0	−·15	Cr_E	4616·81 (Lockyer).	
19·48	19·58	19·53	2	20·22	0	+·69	Cr_E	4618·97	
29·76	29·63	29·70	7	29·48	8	−·22	Fe_E	29·52	
...	34·91	34·91	1	34·66	0	+·25	Cr_E / Fe_E(Lockyer)	4634·25 / 35·50	
37·69	...	37·69	000	...	...	...	...	...	Fe_E Reese 4637·69.
40·07	39·51	39·79	2	39·83	2	−·04			
56·77	57·61	57·19	00	57·42	0	−·23			
61·03	...	61·03	d						
...	64·02	64·02	00	64·04	0	+·02			

d = dark line or space.

TABLE II.—*continued.*

Plate 5423.	Plate 5446.	Mean λ 1919 (1).	Intensity.	Moore and Sanford, 1913. λ (2).	Moore and Sanford, 1913. Intensity.	Difference in λ (2)−(1).	Origin.	Rowland's λ.	Remarks.
4667·15	67·17	67·16	00	67·04	1	−·12			
...	...	...	...	68·78	0	...	...	...	No definite line.
4728·40	27·80	28·10	5	28·35	5	+·25			
30·31	30·54	30·43	d						
32·11	31·87	31·99	1	31·63	2	−·36	...	...	Unknown line in α Cygni.
74·78	74·80	74·79	0	74·82	0	+·03			
4814·49	14·66	14·58	5	14·78	5	+·20			
24·44	24·16	24·30	00	24·64	0+	+·34	Cr_E	4824·33	
...	30·91	30·91	d						
...	45·66	45·66	d						
48·72	48·37	48·55	00	48·21	0	−·34	Cr_E	4848·44	
H_β				H_β					
74·74	74·90	74·82	0	75·19	0	+·37			
89·68	89·75	89·72	0	89·64	3	−·08			
4905·67	05·18	05·43	000	05·80	0	+·37			
24·00	24·22	24·11	5	24·13	8	+·02	Fe_E	4924·11	
5018·97	19·09	19·03	0*	18·78	5	−·25	Fe_E	5018·63	
		Out of range		5159·7	1−				
				69·3	1	...	Fe_E	5169·07	
							Fe_E	69·22	

d = dark line or space.

* Near end of spectrum, not full beam.

Apart from hydrogen, iron, and chromium, for the presence of which in η Argûs there is good evidence, the chromospheric lines in question are ascribed to the following elements in the sun: Ti, Y, V, La, Ca, Zr, Ce, Mn, Sr, Mg, Eu, Co, Ni, Cu, and Nd, but the usual evidence of the presence of these substances in η Argûs is wanting, and therefore the identity of the η Argûs lines with the chromospheric lines quoted is very unlikely.

Moore and Sanford find "that the star lines ascribed to titanium and chromium are displaced farther towards the violet than the iron lines, in the mean about 0·2 A." So many of the strong enhanced lines of titanium are absent from the spectrum of η Argûs, which are present in the chromosphere and in the dark-line spectrum of Nova Aquilæ, that I fail to find any evidence of the presence of that element. Three of the four strong lines which are ascribed in part to titanium in the chromosphere are enhanced iron lines in η Argûs. The remaining lines are weak or faint, and I regard them as chance coincidences, more or less exact, with titanium lines. The evidence for the presence of chromium is stronger, and is shown in Table III.

TABLE III.

The Evidence for Chromium.

Cr Lockyer.		Rowland's ⊙.		E and H,* Spark.	η Argûs. M and S λ (1).	Int.	JL λ (2).	Int.	(1) − ⊙ λ.	(2) − ⊙ λ.
4558·83	10	58·83	3	20	58·56	2	59·47	3	− ·27	+ ·64
88·38	10	88·38	3	20	88·20	3	88·03	3	− ·18	− ·35
4618·97	8	18·97	4d (?)	10	20·22	0	19·53	2	+1·25	+ ·56
34·25	8	34·25	2	10	34·66	0	34·91	1	+ ·41	+ ·66
4824·33	8	24·33	3	10	24·64	0	24·16	00	+ ·31	− ·17
48·44	6	48·44	2	8	48·21	0	48·37	00	− ·23	− ·07
								Means	+ ·21	+ ·21

The enhanced chromium line 4555·16, strong in ε Ursæ Majoris, is almost certainly blended with the enhanced iron line 4556·06, displacing it to the violet.

Taking the five strongest enhanced lines, and including the line 4848·44, we find lines in η Argûs in fairly good agreement, but in the mean displaced 0·2 A to the green, and not as in the mean for enhanced titanium and chromium (M and S) to the violet 0·2 A. Both my measures and those of Moore and Sanford are corrected for shift, and they agree in the mean shift of the six chromium lines. The discrepancies in the wave-lengths must be ascribed to the diffuse character of the lines, and possibly to blending with lines due to the unknown spectrum.

The group of three prominent spark lines of chromium 4254·50, 4274·95, and 4289·89, with intensities 50, 30, 30 (E and H)* respectively, are absent from my list of lines in η Argûs, but the last

* Exner and Haschek.

is present in Moore and Sanford's list. In the Cape plates, continuous spectrum extends from the strong line 4287·5 to the dark space at 4295·4. They are not enhanced lines in Lockyer's list. In the chromosphere (Dyson) they have intensities 3, 3, and 1 respectively. Nova Aquilæ does not show them. None of the other lines in η Argûs agreeing in position with chromospheric lines, ascribed wholly or in part to chromium, except possibly 4616·7, are likely to be due to that element. 4233·2, 4352·3, 4541·8 are enhanced iron lines.

Endeavours to find origins for the lines in η Argûs other than those due to hydrogen, iron, and chromium have met with no success, and I conclude that we have to deal with a spectrum containing numerous lines, some of them very strong, with which we are unacquainted terrestrially.

TABLE IV.

Hubble's Variable Nebula.	η Argûs. Lunt. (1.)	η Argûs. Moore & Sanford. (2.)	Origin in η Argûs.	Intensity in η Argûs. (1.)	(2.)
4099·5	$H\delta$	$H\delta$	$H\delta$		
4176	4175·9	4175·9	Fe_E(duplex)	0 1	1 0 1
4233·7	4233·2	4233·3	Fe_E	5	5
4245·4	4243·9	4244·3	Unknown	8	8
4272	...	4273·8	Unknown	...	0
4299	4296·8	4296·9	Fe_E	0	0
4319	4319·9	4319·7	Unknown	2	2
4342·5	$H\gamma$	$H\gamma$	$H\gamma$		
4352·9	4352·3	4352·3	Fe_E	7	8
4390	4385·9	4385·4	Fe_E	1·5	2
4417	4416·6	4416·4	Unknown	9	9
4469	4468·4	4468·1	Unknown	00	0
4490	4490·3	4490·5	Fe_E(duplex)	4 5	3 3
4518	4517·6	4518·0	Fe_E(duplex)	5 4	5 3
4553	4552·7	4552·7	Fe_E(duplex)	7 6	7 4
4585	4584·1	4584·0	Fe_E	9	9
4630	4629·7	4629·5	Fe_E	7	8
4734	4732·0	4731·6	Unknown	1	2
4863	$H\beta$	$H\beta$	$H\beta$		
4924	4924·1	4924·1	Fe_E	5	8
5016	5019·0	5018·8	Fe_E	0*	5

* Near end of spectrum, not full beam.

The nebular line 4068·8 ± ·5 (Wright) may be represented, but the usual prominent nebular lines are absent, as are also the characteristic Wolf-Rayet lines at 4651 and 4688, and the lines of Novæ in the nebular stage.

Slipher* has called attention to "A new type of nebular spectrum," that of Hubble's variable nebula N.G.C. 2261 and the variable nebula N.G.C. 6729 which has been studied by Knox-Shaw at Helwân, and it appears that the spectra of these objects have many lines in common with the spectrum of η Argûs, particularly amongst the enhanced iron lines, but including some of the unknown lines. In Table IV. the spectra are compared. Slipher disclaims any high accuracy for his wave-lengths, but the comparison shows that the two spectra have much in common, and most of the lines in the variable nebulæ are accounted for.

Miss Cannon, Gill, and Moore and Sanford each note the similarity between the spectra of η Argûs and Nova Aurigæ, and Slipher compares his variable nebula spectrum with the same Nova.

Moore and Sanford found peculiarities in the displacements of the hydrogen lines, and suspected the lines to be double. Their conclusion is that the lines are displaced to the red (*L.O.B.*, 8, 60), unlike the enhanced metallic lines, which are displaced to the violet. In a later note they confirm this view (*L.O.B.*, 8, 134) and give the following velocities:

+46 km., 1912 H_β. +37·8 km., 1913 H_β, H_γ, H_δ. +17, 1914 H_β. and +34·5 H_β, H_γ.

The Cape plates show similar peculiarities. Unfortunately H_β lies in the region towards the end of the spectrum where the focus is falling off rapidly, and not much reliance is placed on measures in that region, as the definition is seriously affected.

Leaving out H_β, and confining the measures to the brightest maxima of the lines, gives the results shown in Table V., which in a general way confirm Moore and Sanford's figures.

TABLE V.

The Hydrogen Lines. Maxima.

Measured λ (corrected). Plate 5423.	Tabular λ. Rowland.	Shift.	Factor. km./s. per λ.	Shift in km./s.	⊙ Corrn. km./s.	Radial Velocity.
H_δ 4102·51	4102·00	+·51	73·10	+37·3	+11·9	+49·2
H_γ 4341·09	4340·63	+·46	69·08	+31·8	+11·9	+43·7
						+46·5
Plate 5446.						
H_δ 4102·57		+·57		+41·7	− 0·8	+40·9
H_γ 4341·46†		+·83		+57·3	− 0·8	+56·5
						+48·7

H_δ and H_γ Maxima. Mean Radial Velocity. Two Plates. +47·6 km./s.

* *Lowell Observatory Bulletin*, No. 81.
† Second maxima to red.

H_β maxima give greater displacements to the red, viz. +74·2 and +97·9 for plates 5423 and 5446 respectively, bringing up the mean radial velocity for the three lines to +60·4 km. per second. Moore and Sanford suspected H_β to have a close companion on the red side.

The hydrogen lines are crossed by more or less definite dark lines on the violet side of the maxima, feebly marked in H but more pronounced in H_γ and H_β.

The measured displacements of the dark lines are rather erratic; excluding H_β the velocity indicated is −19, which by the inclusion of H_β is raised to −33.

The middle of the hydrogen lines gives −13 excluding H_β and +5 km. when H_β is included as the mean of the two plates.

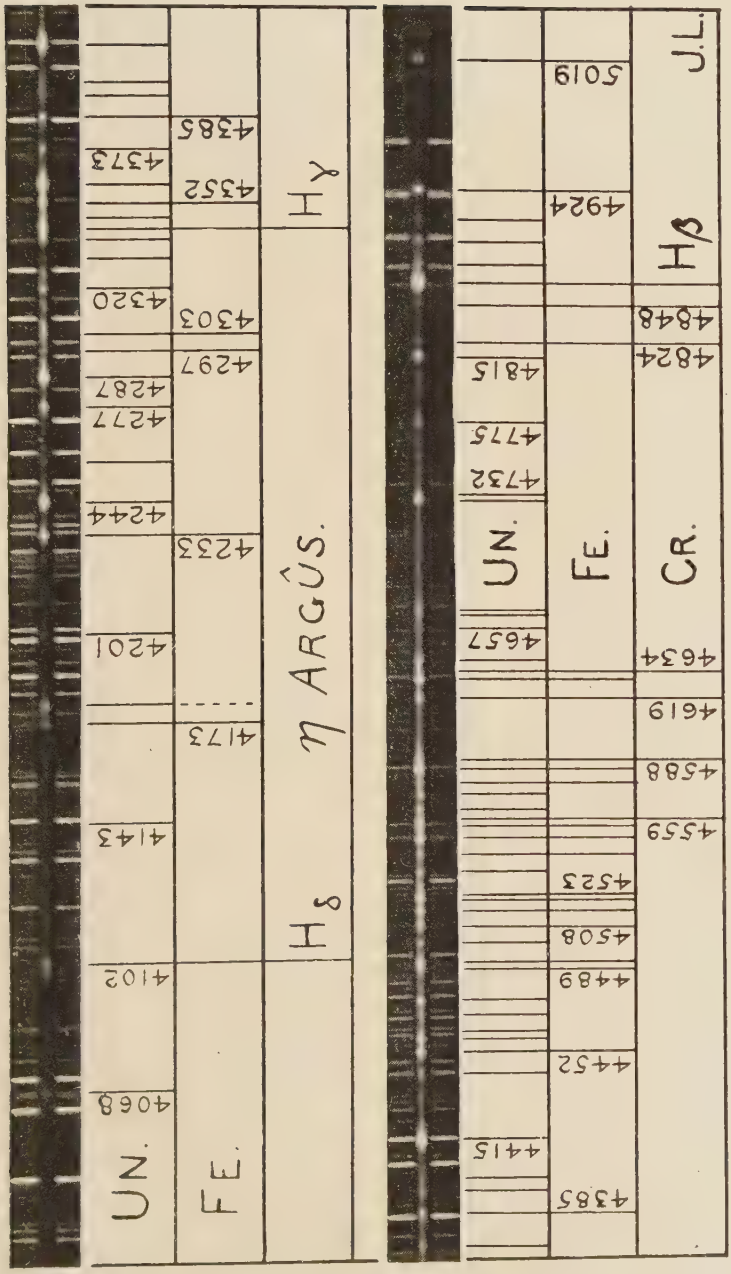
In view of the history of the star, a settling down of an extensive outer hydrogen atmosphere may be assumed to be taking place, and the hemisphere turned towards us might be expected to show a more positive velocity than that of the central more condensed regions.

According to the suggested curve of the variability of the star drawn by Loomis, the brightening of η Argûs is long past due, but, writing in 1914, Innes finds no variation greater than the errors of estimation since 1899, and places its magnitude at 7·8. He gives a full discussion of the variation of magnitude, illustrated by a curve, in the *Annals of the Cape Observatory*, 9, 75 B.

In announcing the duplicity of the star and its non-detection as a double previously, Innes says,* "there is a fair *a priori* probability that the companion is in orbital motion, with a suggestion that the outbursts of light which have occurred in the past have been caused by periastral grazings." In view of this speculation the invariability of the radial velocity, within the limits of error of measurement, is of interest, and the star should be examined periodically with a view to detecting any further changes of magnitude, radial velocity, or spectroscopic composition.

* *M.N.*, 74, p. 698.

Royal Observatory, Cape of Good Hope:
1919 *June* 10.


η ARGÛS.
Hγ
Hδ
UN.
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4352
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Hβ
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5019
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4559
4523
4508
4489
4452
4415
4385

Photographic Parallax Determination of some Southern Stars. By J. Voûte.

In three previous notes (*M.N.*, 77, 152 and 650, and *Astroph. Journ.*, 48, 144) the photographic parallax determinations of a few stars were given. The following table shows all the parallaxes obtained with the Cape astrophotographic refractor from 1914 June to 1917 November.

Particulars about instrument, method of observing, etc., can be found in the first note above-mentioned.

In a few cases only the reduction was made by least square solutions, viz. when no good proper motion was available. For stars in the Boss P.G.C. the proper motions of that catalogue were used; for the p.m. of some of the other stars I am indebted to Professor Parker. The number of comparison stars used varies between eight and twelve; with only a few exceptions these stars were selected not farther than 30 mm. from the plate centre.

Stars for which Parallaxes have been determined.

O. Arg. S. 14318–20. Of this pair of stars, having the same large p.m. of 3″·69, there exist two very good parallax determinations, viz.

Russell	+0″·045 and	+0″·014.
Yerkes	+0″·025	+0″·061.

Boss 2053. Two parallaxes determined by other investigators are in good agreement with that given above, viz.

De Sitter	+0″·064.
Flint II.	+0″·056.

Boss 2279. The parallax of this star has been determined by Flint in his 1st series, viz. $\pi = -0''\cdot06$.

Boss 5180. This star has been observed by Flint in his 1st and 2nd series, viz. $\pm 0''\cdot000$ and $+0''\cdot039$.

O. Arg. S. 20452. The parallax obtained by Flint in his 2nd series is very outstanding, and affected by large systematic errors, viz. $\pi = -0''\cdot24$.

The Binary Systems.

Among the stars observed are a few binary systems. For many binaries hypothetical parallaxes have been computed, most recently by Hertzsprung, Russell, and Luplan-Janssen. Hertzsprung's criterion, that $\pi = 2$ minimum hypothetical π, has been discussed by Luplan-Janssen ("Undersogelser over Dobbelstjerner," *Oversigt K. Danske Vidensk. Selsk.*, 1916, No. 1), and with only a few exceptions shown to be correct (*l.c.*, p. 35).

Boss P.G.C.	Star.	α. 1900. h m	δ. 1900. °	Magn.	Type.	p.m. ″ °	R.V. km./sec.	π relative. ″	″	Mean Mag. Comp. Stars.	No. of Plates.
...	Gou. 32416	0 0	−37·8	8·2	...	0·97 77	+ 26	+0·175	±0·019	9·9	4
4	Lac. 9721	0 1	−49·6	5·8	G	0·53 94	...	+0·000	±0·026	9·5	4
293	κ Tucanæ	1 12	−69·4	5·0	F_8	0·39 72	+ 12·5	+0·165			
294	Lac. 353			7·0		0·39 72		+0·150			
								+0·157	±0·018	10·4	4
1517	Lac. 2124	6 1	−32·2	5·9	B	0·12 36	+102	+0·069	±0·006	9·8	4
2053	171 G Puppis	7 42	−34·0	5·5	G	1·71 351	+100	+0·067	±0 028	9·7	3
2279	11 G Pyxidis	8 29	+31·2	6·7	G_2	1·34 303	...	+0·005	...	10·0	2
3237-8	α Crucis	12 21	−62·6	1·5	B_1	0·05 22	+8+30	±0·000			
3236	Lac. 5147			5·2	B_5		+ 35	±0·000			
								±0·000	...	9·6	4
...	13th magn. star near α Centauri	14 24	−62·3	13·0	(M_G)	3·76 283	...	+0·755	±0·028	11·4	4
...	O. Arg. S. 14318	15 5	−16·0	9·6	G_5	3·69 196	+300	+0·026	±0·023	9·9	4
...	O. Arg. S. 14320			9·2	G_4	3·69 196	+300	+0·003	±0·023	9·9	4
4386	β 416 = Melb. 4	17 12	−34·9	5·9	K_5	1·19 99	− 4·5	+0·173			
...	L.'s companion			10·0				+0·160			
...								+0·166	...	10·0	6
4378	Lac. 7194	17 12	−46·5	5·7	K	0·97 77	...	+0·190	...	10·2	4
5180	5 G Capricorni	20 9	−27·3	5·9	G_2	1·26 99	− 48·5	+0·037	±0·024	9·1	6
...	O. Arg. S. 20452	20 18	−21·7	8·1	F_8	1·18 154	...	+0·067	±0·029	10·3	4
..	Lac. 8760	21 11	−39·2	6·6	...	3·53 251	+ 13	+0·248	±0·028	9·2	4
5725	Lac. 9061	22 9	−41·9	6·7	G	0·96 145	...	−0·010	±0·019	10·0	6
5758	ν Indi	22 16	−72·7	5·4	F	1·45 119	+ 25·6	+0·030	±0·014	9·6	4
6170	Lac. 9697	23 9	−37·8	7·3	...	0·06 23	...	+0·040	±0·026	9·9	4

For the four binaries κ Tucanæ, β 416, Lac. 7194, and α Crucis, for which parallaxes were given in the above list, hypothetical parallaxes were given by the three authorities.

	Observed π.	Hypothetical π.			Type.
		Hertzsprung.	Russell.	Lupl.-Janssen.	
κ Tucanæ	+0″·157	+0″·09	+0″·053	+0″·092	F_8
α Crucis	±0″·000	...	+0″·016	...	B
β 416	+0″·166	...	+0″·144	+0″·182	K_5
Lac. 7194	+0″·190	+0″·192	+0″·208	+0″·182	K

For the last three stars the agreement between observed and hypothetical parallax is very satisfactory. Professor Russell wrote that his small value for β 416 is probably due to the fact that his hypothetical parallaxes are systematically too small for stars of the spectral classes F, G, and K. The hypothetical parallaxes for κ Tucanæ are decidedly smaller than the observed one.

Cape Town:
1919 *June.*

On the Distribution of the Stars down to the Eleventh Magnitude.

By Dr. H. Nort.

(*Communicated by H. C. Plummer.*)

1. In No. 5 of the current volume of the *Monthly Notices*, Dr. A. Pannekoek has published some remarks on the distribution of the stars of * the eleventh magnitude. His investigations proved to confirm my statement † that the structure of the system of these stars is a *three-axial ellipsoid*; that is to say, that the intersection of the plane of the Milky Way with this system is an ellipse instead of a circle, as has previously been assumed. His results, however, differ from mine where he finds two regions of deficiency, one in the direction of Taurus and another in that of Ophiuchus, whereas I found one protuberant part in the direction of the true vertex of Kapteyn's star-streams.

Dr. Pannekoek considered his results sufficiently essential to form the basis of some new hypotheses concerning the structure of the Galactic System. Now, since he rightly observes that the divergency of our results must originate in the fact that our investigations have not been based on the same material, it seems worth while to submit this material to a closer examination.

* Dr. Pannekoek speaks of "the stars *of* the 11th magn." where he means "the stars *down to* the 11th magn." The latter expression must be preferred.

† H. Nort, "The Harvard Map of the Sky and the Milky Way," *Rech. Astr. de l'Observ. d'Utrecht*, vol. vii. chapter xi.

2. In my memoir cited above, the material used consisted of star-counts made by Henie on the Harvard Map of the Sky, a series of 55 glass negatives, covering the whole sky and overlapping each other to some extent at their margins. The mean limiting magnitude at the centre of these plates is 11·0 (vis.), but the individual values of this quantity occasionally differ rather considerably from their mean value, and the plates show, without any exception, a decrease in limiting magnitude from the centre to the margin. Therefore, in order to obtain from Henie's star-counts a homogeneous system of densities, a twofold reduction had to be applied:

(1) A reduction of the densities to a standard limiting magnitude at the centre; for this quantity the value 11·0 has been chosen for all the plates.

(2) A reduction of the densities on the individual plates to the limiting magnitude at the centre. This reduction is called the *distance-correction*.

I may refer to my memoir for the detailed application of these reductions; it resulted in a density-catalogue, which gives at 5000 points about equally divided over the sky the number of stars per square degree from the brightest down to those of the eleventh magnitude.

3. This catalogue of densities has served as a point of departure to my further investigations, but Dr. Pannekoek considers the material in this form not to be homogeneous. On p. 333 of his paper we read: "That in this respect the results of Dr. Nort are far from homogeneous may be seen at once when we plot them on a celestial map. The reduced star-densities of adjacent charts show, in their overlapping parts, considerable systematic differences. Before using them for statistical studies, it is therefore necessary to make them homogeneous." In order to do this, Dr. Pannekoek has followed a method of which he says: "As a first, and for our purpose sufficient, approximation we suppose that the star-densities of Dr. Nort can be reduced to a homogeneous system by multiplying them by factors C that are constant for each Harvard chart. These factors may be found from the overlapping parts of the adjacent charts." From this it follows that Dr. Pannekoek, while applying his corrections, considers the densities on each individual plate to form a homogeneous system, but the various systems of densities to be non-homogeneous because the limiting magnitude at the centre of the plates may be in error.

If Dr. Pannekoek were right in this consideration—I shall presently prove that he is not—the method of correction which he has followed would still be wrong in principle, since, in his procedure, the margins of the plates, which on the Harvard Map are remarkably bad, play the most important rôle. A method by which results chiefly based on the *best* parts of the plates are corrected by data derived from the *worst* parts of the same plates must be condemned.

4. But Dr. Pannekoek's considerations, which led to his system of corrections, are erroneous. The non-homogeneity in my densities is chiefly due to a wrongly applied distance-correction, but not to an error in the limiting magnitude at the centre of the plates. Both through the fact that the plates are bad at the margins and that the marginal fields are few in number, the distance-correction had been a doubtful quantity throughout; moreover, a later investigation * has proved that this correction for a certain number of the plates had been greatly over-estimated, especially for the marginal fields. Though it follows from this that the densities given in my catalogue are partly in error, these errors occur chiefly in the marginal fields, the number of which is small compared with the total number (about 100 on each plate) of the fields which have been counted. Dr. Pannekoek, in applying his method, introduced these errors into *all* the densities, and this procedure, far from being a correction, is a step backwards.

Summarising, I think myself justified in saying that the results obtained by Professor Plummer † and myself, which were based on my original catalogue of densities, are more trustworthy than those which Dr. Pannekoek has derived from his "corrected" densities.

Gouda (Holland):
1919 *July.*

An Analysis of the Magnitude Curves of the Variable Stars in Four Clusters. By H. C. Plummer, M.A.

[The first thirteen paragraphs of the following paper, together with the tables and diagrams referring to ω Centauri, M3, and M5, were prepared at the end of last year. Owing to a delay in publication, Professor Bailey's material for M15 has become available, and a discussion of the results is now added.]

1. Recently noticed similarities ‡ between the short-period variables, particularly those belonging to the merihemeral group, and the long-period variables, particularly those assigned by Mr. Phillips § to Group II., had led me to begin an analysis of the variables in clusters, when I received a suggestion from Professor E. C. Pickering that the analysis of Professor Bailey's material ‖ was very desirable. Accordingly the work, which had only just been begun, has been finished, and the results in a tabular form are appended to this paper. For each of the three clusters ω Centauri, M3, and M5 the stars are arranged in the order of their

* H. Nort, "The Distance-Correction for the Plates of the Harvard Map of the Sky," *Proceedinys of the Royal Academy of Sciences at Amsterdam*, 1919 Jan. 25.

† H. C. Plummer, "On the Distribution of the Stars," *M.N.*, 78, 668.

‡ *M.N.*, 78, 161. § *J.B.A.A.*, 27, 2.

‖ *Harvard Annals*, 38, 78 (parts 1 and 2).

periods. The numbers given in the first column are those assigned by Bailey.

2. In the original memoirs twenty-four equidistant ordinates are tabulated for each magnitude curve. This is extremely convenient for the purpose of harmonic analysis. The curves appear to be remarkably accurate when the circumstances are considered. The plates are of several kinds, taken over a number of years with different instruments, and the stars are faint and often congested. In view of these difficulties it seemed that the analysis might be confined, for statistical purposes and at least in the first instance, to the first three harmonics. It seemed further that these terms could be determined with sufficient accuracy from the twelve alternate ordinates. As this meant a considerable saving of labour in dealing with so much material, this course has been followed.

3. The first step, as usual, is to express the variable magnitude in the form

$$m = m_0 + \Sigma(a_n \cos n\theta + b_n \sin n\theta)$$

where θ increases proportionately to the time by 2π in a period and is reckoned from the adopted epoch of maximum. The mean magnitude m_0 is tabulated. The second step is to derive the corresponding form

$$m - m_0 = \Sigma r_n \sin(n\theta + \theta_n).$$

The coefficients, r_1, r_2, r_3, and the phases of maximum, θ_1, θ_2, θ_3, are tabulated. By a simple change of epoch the alternative form

$$m - m_0 = -r_1 \cos\phi + r_2 \cos(2\phi - \phi_2) + r_3 \cos(3\phi - \phi_3)$$

is obtained, where

$$\phi_2 = 270^\circ + 2\theta_1 - \theta_2, \quad \phi_3 = 3\theta_1 - \theta_3.$$

The phases ϕ_2, ϕ_3 are tabulated. The advantage of the last form, in which the phase of the first harmonic is 180°, is that it is independent of any error in assigning the epoch of maximum, though the difficulty is less with the cluster variables than with other classes of stars, because their maxima are in general fairly sharply defined.

4. In the cluster ω Centauri Bailey distinguishes three subclasses of variables, *a*, *b*, and *c*. These are recorded in the third column of Table I. The distinction between the classes *a* and *b* rests on a more marked tendency in *a* towards a prolonged stationary phase at maximum. This is associated with a larger range and a shorter period. An inspection of Table I. will show that the difference does not appear in the first three harmonics. It is therefore to be inferred that the difference is connected with the higher harmonics, and may perhaps be explained by a secondary disturbance of the kind discussed in a recent paper* on RR Ceti. Possibly the shorter period is directly responsible for the disturbance. The change of class occurs at the period sixteen hours approximately.

* *M.N.*, 79, 194.

5. The number of stars which can be assigned to the subclasses a and b together is fifty-seven. Their representative points (ϕ_2, ϕ_3) are shown in fig. 1. The two crosses represent the stars

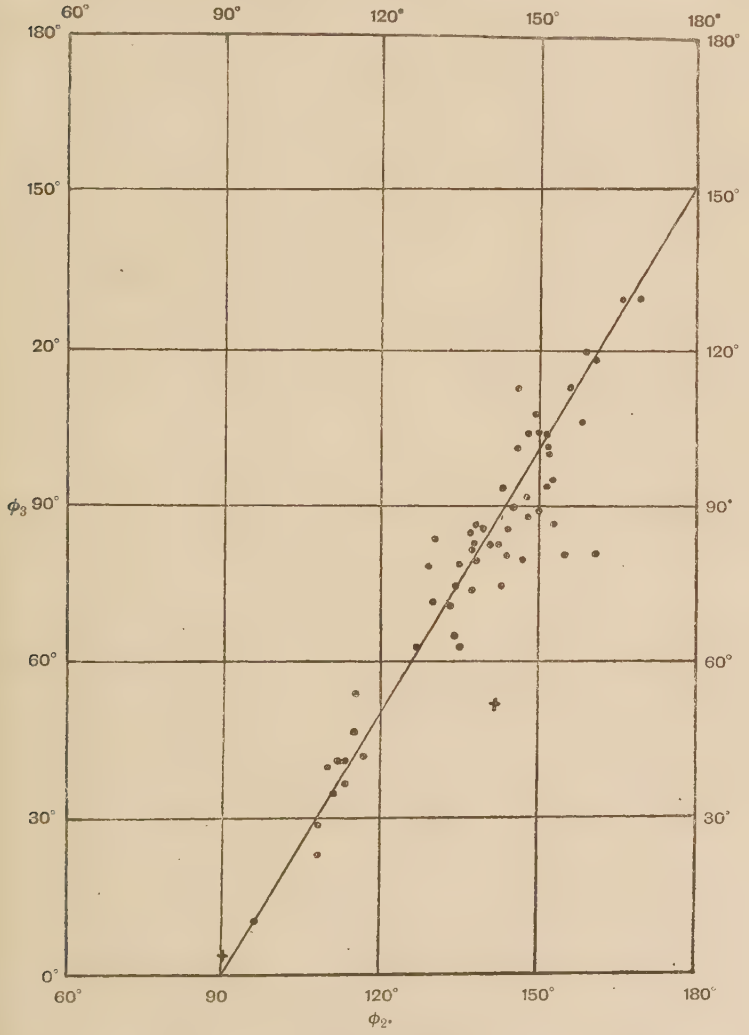

FIG. 1.—ω Centauri.

No. 60 (period 1·3 d.) and No. 1 (period 29·3 d.), which may belong to the foreground and not to the cluster. The two long-period stars, Nos. 42 and 2, are apparently of quite abnormal type. Fully a third of the ninety-five stars in the list, thirty-three in

fact, seem to belong to sub-class *c*. These may conveniently be considered later. They are excluded from fig. 1.

6. The representative points of all the variables, 110 in

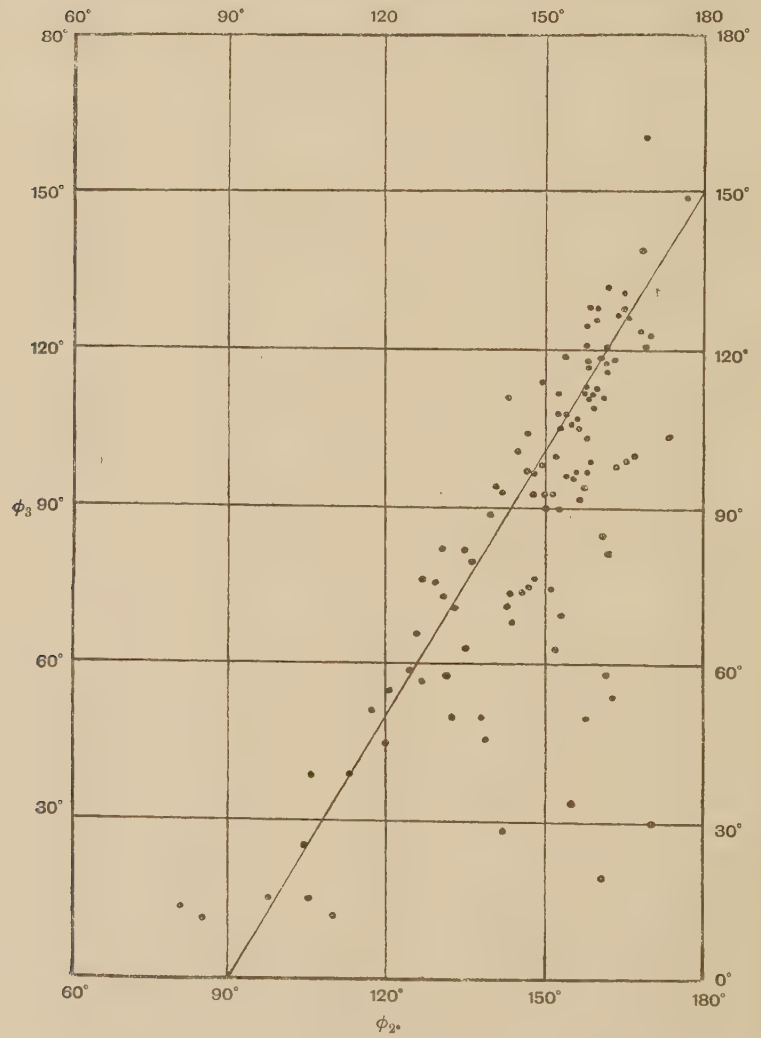

FIG. 2.—M3.

number, in the cluster M3 are plotted in fig. 2. These stars are attributed exclusively to sub-class *a*. This coincides with the fact that 16^h is practically an upper limit to the periods in this cluster. The variables are remarkable for their large range, commonly amounting to $2^m \cdot 5$. The magnitude scale is subject to revision

and may be exaggerated. But a large reduction is needed to bring the results into line with all other cluster variables.

7. In the cluster M5 stars of sub-class *c* reappear, though only to the extent of eight in a total of seventy-two. Two stars, however, might apparently be added to the group: Nos. 68 and 15 (periods ·502 and ·508 d.). Bailey now suggests that such stars should be treated as having double maxima and double periods. The eight stars are analysed on that assumption in Table III., but in Table IIIA. they are treated on the alternative hypothesis that the single period is the true one, and that the two halves of the double curve are identical. There are also three stars of longer period, belonging either to the cluster or to the foreground. These are represented by crosses in the phase diagram (fig. 3), in which are plotted the representative points of the sixty-one variables of normal cluster type. No distinction between sub-classes *a* and *b* has in this case been made by Bailey, though a few of the periods are in excess of 16^h.

8. The three phase diagrams show a certain resemblance, but at the same time each of the three clusters is seen to have an individuality of its own, on account of which the diagrams have not been combined in a single figure. The correlation between ϕ_2 and ϕ_3 is evident, and may fairly be represented by the line

$$\phi_2 - 0{\cdot}6\,\phi_3 = 90^\circ$$

between the points (90°, 0°) and (180°, 150°). The corresponding relation found by Mr. Phillips for the long-period stars of Group II. may be written

$$\phi_2 - 0{\cdot}6\,\phi_3 = 76^\circ.$$

The lines are parallel, and it will be seen that the direction is fairly sharply defined in the case of the cluster variables. The constants are not widely different, and indeed many of the representative points for the long-period variables will be found to lie quite close to the cluster line. Nevertheless, if the line found by Mr. Phillips is drawn on these diagrams, it forms a boundary line on the left, transgressed by no more than one or two of the 228 * cluster points. There is, on the contrary, a tendency for the cluster points to diffuse to the right of the line now laid down, which is most marked in the case of M3. The cluster M3 also differs from the other two in showing a large concentration beyond the line $\phi_2 = 150^\circ$, whereas the distribution for ω Centauri and M5 almost stops short at this point. The distribution is most uniform and compact in the case of the cluster M5. It seems possible that some of the scattering of the points in these diagrams may be attributed to unavoidable errors in the difficult original investigations. In any case, they are not sufficiently serious to mask the approximate phase relation.

9. While the distinction between sub-classes *a* and *b* is not apparent in the first three harmonics, stars of sub-class *c* are at once obvious in the analysis. They constitute about 35 per cent. of the variables in ω Centauri, not more than 15 per cent. in M5,

* The thirty similar stars in M15 add no exception.

and apparently they do not occur at all in M3. The magnitude curves have a range of $0^m{\cdot}5$ or $0^m{\cdot}6$, and are practically pure sine curves. For several reasons Bailey's suggestion that they are to

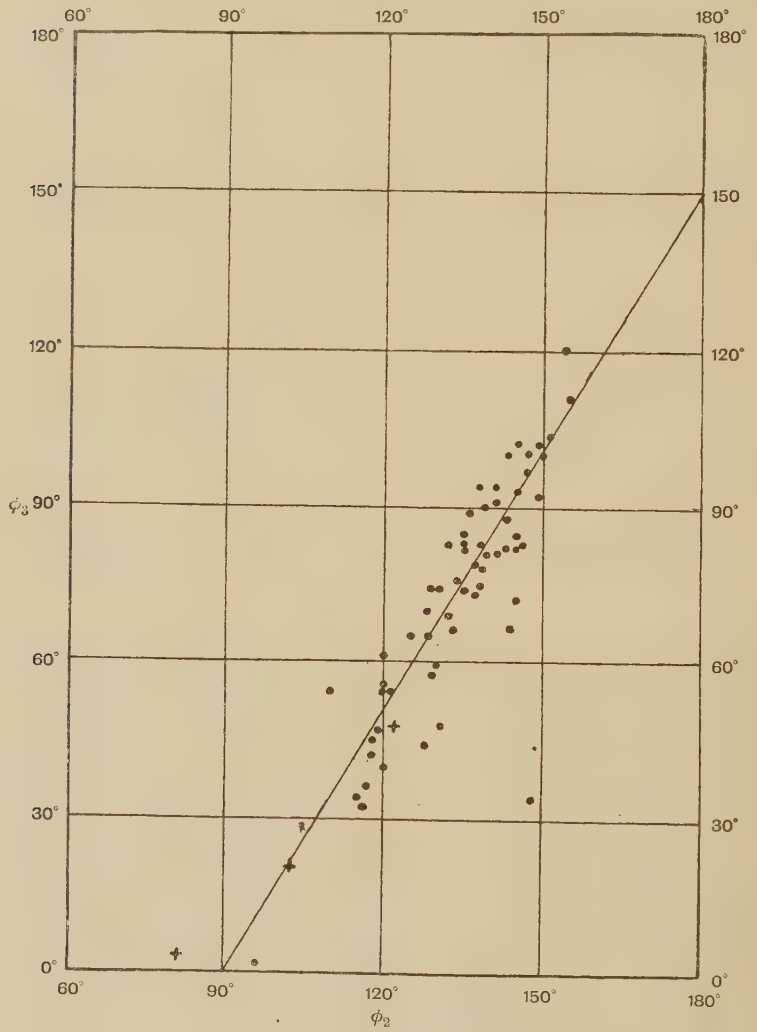

FIG. 3.—M5.

be explained by the composition of two unresolved independent stars of normal cluster type seems highly improbable. The proportional occurrence in the different clusters and the uniform type and range of variation are clearly against this idea. Bailey himself states clearly another objection. The normal variables are very

uniform in mean magnitude, and the mean magnitude of an unresolved pair should be $0^m{\cdot}75$ brighter than that of a single star. But it is not. It may be observed that star No. 23 (period ·598 d.) in M3 is an illustration. This star is a double measured as one mass, and the mean magnitude (15·38) stands out at a glance among the other stars.

10. When analysed with the double period, as in Table III., these stars show a variation naturally confined almost entirely to the second harmonic, and no phase relation is apparent. When the analysis is made with the single period, as in Tables I. and IIIa., and those cases are excluded where a coefficient less than $0^m{\cdot}01$ is involved, so that the corresponding phase is quite uncertain, the representative phase points tend to cluster about the lower end (90°, 0°) of the line drawn in figs. 1–3, or about a downward continuation of that line. The scattering is considerable, but not remarkable when the smallness of the coefficients is considered. This is slight evidence in favour of the single period.

11. But on another view the double period can be very simply explained by a modification of Professor Bailey's hypothesis. Instead of regarding the variation in sub-class *c* as arising from the accidental combination of a pair of independent stars belonging to the normal cluster type, it may be attributed to eclipsing binary systems of the same type as W Ursæ Majoris or RR Centauri. It seems strange that this very obvious suggestion has apparently not been made before. The hypothesis seems as free from objection * as it is simple. In such cases the variation is due largely to the ellipsoidal figure of the rotating components, and the magnitude curve is almost a pure sine curve. W Ursæ Majoris is the densest system known, and if any doubt remained as to the binary interpretation, it seems to be completely removed by the spectroscopic observations † of Adams and Joy, who have found the spectra of both components to be visible near maximum. In length of period RR Centauri is a closer example of the stars found in ω Centauri and M5.

12. If the stars of sub-class *c* are simply eclipsing binaries, what is their relation to the stars in sub-classes *a* and *b*? Can it be that the latter are ellipsoidal stars which have escaped or are unripe for division by fissure, but manifest the effects of rotational instability? It may or may not be relevant to notice that the magnitudes of their second harmonics are of the same order as the principal term in the other class. If this term seems a little larger, it may be that, standing alone, its smaller values have escaped observation and record. Still larger coefficients occur among the second harmonics in M3.

13. All attempts to found an hypothesis on a single undivided star have against them the spectroscopic evidence as commonly interpreted. There is an apparent difficulty connected with this evidence, even when taken by itself, which can scarcely be

* This view is qualified in § 14 below.

† *Popular Astronomy*, 26, 634.

ignored. It is well known that in the early days of spectroscopic binaries the objection was raised that the distribution of the periastra was not according to probability; that, in fact, the direction opposite to the sun was unduly favoured. With the accumulation of more numerous examples this remark in its general application has practically lost its point. But when the attention is confined to the stars of δ Cephei type, with RR Lyræ as the sole representative of the normal cluster variable, the difficulty returns. A table of fourteen stars had been prepared but need not be reproduced, because the material is essentially contained in Professor Eddington's table I. (p. 4). It differed from the latter in omitting SU Cassiopeiæ, with its circular orbit, and substituting Polaris, period 3·97 days, eccentricity 0·13 and $\omega = 80°$. It also gave Moore's elements of δ Cephei ($e = 0·48$, $\omega = 85°$) and Wright's final elements of η Aquilæ ($e = 0·49$, $\omega = 69°$). The table then shows that no periastron of the bright component falls within $\pm 60°$ of $\omega = 270°$ (the direction of the sun), but that within $\pm 21°$ of 90° are to be found ten periastra out of fourteen, and that when the eccentricity exceeds 0·22 (in nine cases) all the periastra fall within this range. This alone seems improbable enough to cast suspicion on the orbital interpretation. Yet there can be no doubt that the spectrograms register the variable radial velocity of something definite.

14. Only a fortnight before his lamented death Professor Pickering sent me an advance proof of the concluding part of *Harvard Annals*, 78, containing Professor Bailey's magnitude curves of the variables in M15. These curves have now been analysed, and the results are tabulated as for the other clusters in Table IV. As there are only thirty stars belonging to sub-classes *a* or *b*, it has not been thought necessary to reproduce the corresponding phase diagram. It is enough to say that the distribution of the representative points resembles essentially that shown in the ω Centauri diagram. The cluster M15 also resembles, and indeed exceeds, ω Centauri in the high proportion of stars of sub-class *c* which it contains. This additional evidence throws a distinct doubt on the soundness of the suggestion made in § 11 above, that these stars are eclipsing binaries. For the feature noticed in § 10 is confirmed. The representative points tend towards the same phase line as for the other classes. They fall near its lower end for the most part, and though some would require a downward continuation of the line, the majority of the points come within the limits of the diagrams given for the other clusters. The evidence is the more remarkable because it rests on the phases of the third harmonic, and the amplitude of this term is extremely small for stars of the class in question. It appears, however, that this small term must be taken seriously as indicating a physical continuity between sub-class *c* and sub-classes *a* and *b*. At the same time, the possibility that sub-class *c* may contain eclipsing binaries of the type of RR Centauri deserves the special investigation of a few individual cases before being definitely set aside.

15. In conclusion, the extensive material analysed in this paper is summarised in the following Table V. The distinction between the numbers of stars in the respective sub-classes is not drawn on critical lines. This will account for the discrepancy between the fifty-six *a* or *b* stars here recorded for ω Centauri and the fifty-seven points appearing in fig. 1.

TABLE V.

Cluster.	Sub-classes *a* or *b*.	Sub-class *c*.	Period $>1^d$.	Total.
ω Centauri	56	34	5	95
M3	110	0	0	110
M5	61	8	3	72
M15	30	29	1	60
Total	257	71	9	337

TABLE I.—*ω Centauri.*

No.	Period.	Sub-class.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d			m	m	m					
19	·300	*c*	13·95	·38	·04	·01	260°	332°	68°	98°	352°
123	·321	*c*	13·56	·25	·07	·02	243	282	329	114	40
124	·332	*c*	13·60	·31	·07	·04	244	285	328	113	44
105	·335	*c*	13·71	·27	·06	·00	241	289	(180)	103	(183)
82	·336	*c*	13·73	·26	·04	·03	248	350	53	56	331
76	·338	*c*	13·48	·26	·05	·02	239	321	10	67	347
101	·341	*c*	13·71	·24	·04	·01	269	298	27	150	60
126	·342	*c*	13·66	·31	·04	·02	241	312	17	80	346
64	·344	*c*	13·65	·25	·08	·03	231	301	330	71	3
83	·357	*c*	13·65	·30	·02	·01	249	326	333	82	54
71	·357	*c*?	13·60	·35	·04	·02	261	68	42	4	21
89	·375	*c*	13·73	·29	·04	·02	258	269	323	157	91
10	·375	*c*	13·59	·30	·03	·01	260	328	67	102	353
14	·377	*c*	13·72	·31	·06	·02	252	277	274	137	122
36	·380	*c*	13·58	·22	·03	·01	248	266	346	140	38
72	·385	*c*	13·59	·26	·04	·01	258	358	111	68	303
50	·386	*c*	13·57	·29	·05	·01	268	279	63	167	21
12	·387	*c*	13·47	·26	·04	·02	261	34	120	38	303
35	·387	*c*	13·55	·37	·02	·02	263	0	100	76	329
81	·389	*c*	13·76	·34	·04	·00	246	358	(117)	44	(261)
70	·391	*c*?	13·62	·24	·04	·04	247	310	32	94	349
39	·393	*c*	13·66	·29	·04	·01	249	32	214	16	173
22	·396	*c*	13·63	·28	·06	·03	219	287	325	61	332
87	·396	*c*	13·68	·26	·04	·02	241	338	13	54	350
30	·404	*c*?	13·57	·23	·03	·01	245	338	326	62	49

TABLE I.—*continued.*

No.	Period.	Sub-class.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d			m	m	m	°	°	°	°	°
66	·407	*c*	13·58	·24	·05	·01	283	123	236	353	253
117	·422	*c*	13·63	·26	·09	·03	242	263	300	131	66
75	·422	*c*	13·51	·26	·03	·01	266	198	30	244	48
77	·426	*c*?	13·63	·22	·04	·02	238	267	323	119	31
24	·462	*c*	13·58	·25	·06	·01	297	215	315	289	216
47	·485	*c*?	13·41	·27	·03	·01	269	66	135	22	312
130	·493	*a*	13·82	·54	·36	·17	235	234	232	146	113
74	·503	*a*	13·75	·55	·25	·16	230	227	236	143	94
23	·511	*a*	13·94	·46	·21	·12	238	234	254	152	100
107	·514	*a*	13·87	·45	·25	·12	244	237	253	161	119
5	·515	*a*	13·93	·53	·22	·14	233	226	250	150	89
59	·518	*c*?	13·82	·36	·12	·06	230	241	251	129	79
8	·521	*a*	13·86	·58	·28	·17	230	217	235	153	95
9	·523	*a*	13·91	·53	·23	·13	232	228	235	146	101
68	·534	*c*	13·41	·24	·03	·00	273	284	(117)	172	(342)
120	·549	*a*	13·80	·46	·18	·10	242	256	283	138	83
100	·552	*a*?	13·46	·40	·10	·04	242	260	301	134	65
67	·564	*a*	13·87	·40	·20	·10	235	224	232	156	113
44	·568	*a*	13·99	·33	·17	·11	233	226	235	150	104
106	·570	*a*	13·69	·51	·19	·09	243	243	282	153	87
113	·573	*a*	13·46	·52	·25	·16	234	220	236	158	106
51	·574	*a*	13·71	·50	·19	·11	240	239	266	151	94
73	·575	*a*	13·77	·51	·22	·11	233	231	249	145	90
55	·582	*a*	13·94	·38	·16	·08	239	245	282	143	75
25	·588	*a*?	13·73	·42	·15	·08	226	252	278	110	40
45	·589	*a*	13·68	·50	·24	·15	228	225	241	141	83
125	·593	*a*	13·76	·50	·24	·15	230	218	229	152	101
108	·594	*a*	13·40	·29	·11	·06	228	211	243	155	81
33	·602	*a*	13·69	·50	·22	·15	225	218	232	142	83
49	·605	*a*	13·89	·39	·18	·10	237	235	243	149	108
79	·608	*a*	13·86	·51	·22	·15	223	219	235	137	74
118	·612	*a*	13·74	·50	·26	·12	244	229	242	169	130
21	·615	*c*	13·38	·22	·06	·01	303	224	307	292	242
20	·616	*a*	13·82	·55	·24	·16	229	220	235	148	92
27	·616	*a*?	13·96	·22	·13	·10	239	229	237	159	120

TABLE I.—*continued.*

No.	Period.	Sub-class.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d			m	m	m	°	°	°	°	°
62	·620	*a*	13·50	·43	·19	·12	223	222	234	134	75
32	·620	*a*	13·52	·44	·19	·13	224	214	231	144	81
18	·622	*a*	13·77	·55	·24	·14	220	217	229	133	71
96	·624	*a*?	13·52	·35	·16	·08	240	251	274	139	86
4	·627	*a*	13·66	·53	·19	·11	230	253	288	117	42
115	·630	*a*	13·82	·43	·23	·13	232	226	232	148	104
40	·634	*a*	13·72	·44	·21	·12	226	218	232	144	86
122	·635	*a*	13·81	·49	·21	·12	227	226	241	138	80
86	·648	*a*	13·83	·53	·20	·12	230	240	246	130	84
69	·653	*a*	13·72	·46	·18	·10	240	253	275	137	85
132	·656	*b*?	13·67	·47	·17	·09	229	241	264	127	63
52	·660	*b*?	13·11	·35	·12	·07	230	223	250	147	80
41	·663	*a*	13·68	·46	·19	·12	229	231	245	137	82
13	·669	*b*	13·61	·44	·22	·12	226	227	239	135	79
46	·687	*b*	13·69	·46	·18	·09	235	232	257	148	88
88	·690	*b*	13·48	·35	·10	·07	221	244	280	108	23
102	·691	*b*	13·71	·40	·18	·09	255	269	301	151	104
97	·692	*b*	13·80	·43	·17	·07	253	250	269	166	130
7	·713	*b*	13·70	·38	·17	·09	236	244	261	138	87
34	·734	*b*	13·72	·38	·16	·08	222	246	277	108	29
85	·743	*b*	13·66	·29	·21	·07	231	276	322	96	11
99	·766	*b*	13·43	·49	·19	·09	246	272	306	130	72
54	·773	*b*	13·71	·31	·12	·06	223	221	246	135	63
38	·779	*b*	13·82	·34	·22	·06	239	275	320	113	37
26	·785	*b*	13·71	·34	·13	·06	236	269	307	113	41
15	·811	*b*	13·54	·38	·16	·08	231	260	292	112	41
63	·826	*b*?	13·78	·21	·12	·07	230	255	276	115	54
3	·841	*b*	13·56	·39	·12	·06	237	273	316	111	35
104	·869	*b*?	13·74	·27	·10	·03	258	265	333	161	81
91	·895	*b*	13·71	·42	·11	·08	245	285	328	115	47
60	1·349		12·79	·48	·13	·06	231	230	281	142	52
29	14·75		11·84	·52	·11	·04	250	65	259	345	131
1	29·34		10·48	·49	·30	·10	225	270	311	90	4
42	297·0		13·04	·37	·98	·11	346	247	316	355	2
2	484		13·62	·56	1·50	·16	248	224	237	182	147

TABLE II.—M3.

No.	Period.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d	m	m	m	m	°	°	°	°	°
19	·412	16·31	·65	·19	·12	236	240	319	142	29
86	·414	15·85	·83	·16	·17	220	269	286	81	14
131	·437	15·66	·70	·16	·09	235	276	319	104	26
107	·447	15·81	·67	·25	·12	247	277	324	127	57
72	·456	16·10	1·14	·51	·19	243	238	272	158	97
77	·459	16·08	1·11	·38	·16	236	236	274	146	74
28	·476	15·87	·71	·43	·24	242	226	227	168	139
25	·480	16·07	·99	·43	·12	246	237	250	165	128
22	·481	16·05	1·09	·51	·23	240	245	259	145	101
13	·483	15·81	·99	·32	·22	219	223	238	125	59
79	·484	15·99	·83	·32	·18	229	241	251	127	76
41	·486	16·09	·87	·37	·04	244	242	265	156	107
20	·491	15·85	1·07	·41	·22	241	271	308	121	55
74	·492	16·27	·83	·47	·25	237	218	225	166	126
121	·493	16·00	·81	·29	·08	243	226	246	170	123
32	·495	15·92	1·00	·47	·19	241	232	250	160	113
56	·495	15·73	·66	·21	·05	243	276	324	120	45
7	·497	15·85	·94	·51	·26	238	224	222	162	132
118	·499	16·18	·94	·37	·21	230	220	240	150	90
96	·499	15·94	·97	·41	·26	226	229	247	133	71
83	·501	15·77	1·23	·27	·22	224	260	296	98	16
54	·502	15·93	·84	·42	·22	239	230	246	158	111
76	·502	16·05	·99	·50	·35	226	220	225	142	93
92	·504	16·05	·78	·42	·35	220	212	250	138	50
97	·504	15·89	·46	·14	·05	223	271	297	85	12
53	·505	16·06	·81	·48	·33	235	226	226	154	119
5	·506	16·03	1·04	·47	·28	228	216	231	150	93
44	·506	16·04	·91	·35	·08	266	281	327	161	111
132	·507	15·96	·61	·32	·17	228	217	226	149	98
11	·508	15·93	·98	·45	·23	233	220	242	156	97
16	·511	15·97	1·02	·29	·16	244	281	321	117	51
111	·513	15·97	·68	·32	·15	237	221	233	163	118
57	·513	16·06	·94	·40	·17	236	229	258	153	90
50	·513	16·14	·98	·45	·18	230	204	231	166	99
115	·514	16·01	1·06	·46	·15	234	227	249	151	93

TABLE II.—*continued.*

No.	Period.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d		m	m	m	°	°	°	°	°
6	·514	16·07	·97	·46	·28	241	263	287	129	76
116	·515	16·04	·90	·46	·21	238	234	242	152	112
52	·516	15·91	·85	·43	·20	236	220	232	162	116
18	·516	16·15	·78	·32	·16	239	252	277	136	80
21	·516	16·18	·94	·36	·17	236	238	274	144	74
58	·517	15·54	·91	·12	·07	253	311	23	105	16
90	·517	16·11	·82	·37	·21	243	240	264	156	105
119	·518	15·99	1·07	·57	·29	230	212	217	158	113
113	·518	16·33	·86	·54	·33	237	224	225	160	126
68	·519	15·76	·66	·27	·06	259	261	317	167	100
108	·520	16·13	·90	·38	·22	222	206	229	148	77
1	·521	15·97	1·04	·41	·17	242	233	281	161	85
61	·521	16·03	·93	·40	·17	248	249	290	157	94
94	·524	16·25	·96	·48	·21	249	249	275	159	112
82	·525	16·09	1·12	·32	·17	235	219	325	161	20
33	·525	16·14	·82	·42	·21	242	247	261	147	105
81	·529	16·07	·95	·36	·14	232	220	240	154	96
15	·530	16·05	·86	43	·25	233	217	230	159	109
91	·530	16·20	·74	·41	·27	226	221	224	141	94
55	·531	15·90	·96	·40	·28	208	220	225	106	39
35	·531	16·11	·87	·46	·23	233	214	222	162	117
109	·534	16·08	·90	·32	·16	231	229	262	143	71
126	·535	15·97	·45	·21	·06	263	259	280	177	149
110	·536	15·92	·74	·38	·19	231	218	225	154	108
45	·537	16·33	·82	·41	·23	246	249	270	153	108
125	·539	16·07	·61	·18	·06	258	263	0	163	54
80	·539	15·94	·98	·30	·19	237	251	301	133	50
43	·541	15·84	·97	·37	·14	237	249	288	135	63
47	·541	16·07	1·00	·26	·06	266	299	327	143	111
9	·542	16·16	·93	·48	·26	236	220	227	162	121
123	·545	16·33	·90	·43	·16	244	230	248	168	124
36	·546	16·16	·93	·43	·19	250	255	294	155	96
106	·547	16·16	·73	·39	·19	236	227	242	155	106
49	·548	16·05	·95	·38	·19	246	250	315	152	63
89	·548	15·99	·82	·40	·24	235	240	256	140	89

TABLE II.—*continued.*

No.	Period.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_1.	ϕ_2.
	d	m	m	m	m	°	°	°	°	°
71	·549	16·18	·72	·37	·18	258	266	286	160	128
133	·551	15·78	1·01	·27	·19	223	246	296	110	13
40	·552	16·16	·98	·45	·19	231	214	230	158	103
100	·558	16·26	·55	·15	·05	255	276	337	144	68
3	·559	15·89	1·04	·33	·21	232	242	278	132	58
34	·559	16·14	·81	·37	·11	244	239	273	159	99
38	·561	16·12	1·00	·38	·17	242	241	296	153	70
69	·567	16·04	·87	·27	·11	245	242	325	158	50
67	·568	16·11	·90	·48	·26	243	237	241	159	128
10	·569	16·08	·94	·40	·13	242	230	268	164	98
63	·570	16·14	·72	·37	·21	242	236	254	158	112
104	·571	16·03	·92	·41	·20	245	252	282	148	93
17	·576	16·32	·72	·39	·21	240	225	229	165	131
137	·577	16·09	·72	·40	·28	224	223	230	135	82
27	·580	16·17	·74	·35	·10	264	269	271	169	161
31	·581	15·83	·97	·28	·14	243	234	287	162	82
51	·586	16·18	·79	·33	·11	241	223	242	169	121
39	·587	16·08	·90	·41	·20	241	244	266	148	97
59	·589	16·23	·78	·38	·22	232	222	236	152	100
42	·590	15·74	1·01	·45	·22	229	242	261	126	66
84	·596	16·13	·65	·36	·21	249	259	273	149	114
114	·598	16·12	·83	·33	·13	243	245	294	151	75
26	·598	15·94	·94	·36	·16	245	239	257	161	118
23	·598	15·38	·73	·24	·15	234	265	303	113	39
117	·601	16·26	·74	·31	·12	243	240	277	156	92
93	·602	16·09	·92	·33	·10	272	284	66	170	30
64	·605	16·17	·67	·31	·15	248	248	259	158	125
128	·606	16·02	·74	·31	·05	254	244	298	174	104
78	·612	15·90	·92	·44	·15	261	268	296	164	127
46	·612	16·33	·53	·26	·12	244	240	254	158	118
134	·617	16·17	·6	·28	·14	232	221	231	153	105
66	·620	16·04	·60	·28	·12	247	246	264	158	117
48	·628	16·05	·72	·23	·10	249	261	283	147	104
14	·635	15·71	1·09	·23	·12	265	285	41	155	34
101	·644	16·04	·57	·22	·09	258	279	317	147	97

TABLE II.—*continued.*

No.	Period.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d		m	m	m	°	°	°	°	°
62	·652	16·10	·67	·26	·04	265	278	17	162	58
88	·654	15·70	·53	·29	·15	248	248	263	158	121
24	·665	15·88	·88	·31	·18	239	249	311	139	46
65	·668	15·97	·77	·41	·28	225	229	233	131	82
60	·708	16·13	·67	·35	·18	233	245	266	131	73

TABLE III.—M5.

No.	Period.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d		m	m	m	°	°	°	°	°
4	·450	15·13	·55	·25	·15	227	221	233	143	88
29	·451	15·15	·43	·17	·08	232	236	242	138	94
32	·458	15·18	·57	·26	·14	240	245	258	145	102
31	(·462)	15·03	·05	·35	·03	246	233	337	169	41
18	·464	15·20	·39	·16	·09	231	221	230	151	103
12	·468	15·23	·65	·27	·16	237	252	282	132	69
19	·470	15·22	·66	·25	·12	240	253	281	137	79
27	·470	15·13	·55	·14	·09	220	219	252	131	48
38	·470	15·14	·49	·21	·13	228	231	241	135	83
24	·478	15·18	·46	·21	·10	240	235	249	155	111
65	·481	15·02	·56	·18	·10	211	215	237	117	36
14	·487	15·06	·45	·12	·05	247	260	314	144	67
41	·489	15·17	·68	·29	·14	238	241	261	145	93
37	·489	15·26	·67	·32	·16	234	237	248	141	94
55	·491	15·09	·20	·09	·04	243	242	249	154	120
58	·492	15·09	·58	·28	·13	240	247	260	143	100
88	(·494)	15·14	·04	·26	·02	72	244	228	170	348
7	·494	15·25	·68	·25	·13	236	247	276	145	72
69	·495	15·00	·59	·21	·12	230	227	248	143	82
44	(·496)	14·95	·03	·28	·02	137	232	238	312	173
63	·498	15·14	·58	·24	·11	240	241	268	149	92
79	(·500)	14·89	·05	·26	·02	244	250	157	148	215
33	·501	15·31	·56	·25	·15	231	234	250	138	83
52	·502	15·01	·51	·21	·11	237	246	273	138	78
68	·502	15·00	·22	·06	·02	239	292	355	96	2

TABLE III.—*continued.*

No.	Period.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d		m	m	m	°	°	°	°	°
71	·502	15·19	·55	·24	·15	233	235	248	141	91
80	(·503)	15·00	·09	·22	·04	66	221	239	181	319
15	·508	15·08	·25	·05	·02	238	268	309	118	45
13	·513	14·91	·45	·17	·08	242	247	266	147	100
1	·522	15·17	·56	·24	·13	245	251	273	149	102
2	·526	15·11	·46	·18	·02	261	284	29	148	34
85	·527	15·22	·50	·20	·10	227	225	240	139	81
10	·531	15·06	·51	·24	·14	229	233	245	135	82
56	·535	15·18	·50	·21	·12	239	256	274	132	83
47	·540	15·22	·62	·28	·17	216	222	234	120	54
59	·542	15·11	·46	·22	·14	233	229	242	147	97
28	·544	15·26	·55	·21	·12	225	232	250	128	65
64	·545	15·27	·55	·24	·12	234	237	261	141	81
5	·546	15·12	·60	·24	·09	240	252	285	138	75
8	·546	15·22	·51	·23	·15	234	242	253	136	89
6	·549	14·87	·38	·18	·10	237	255	277	129	74
83	·553	15·32	·48	·25	·13	246	263	288	139	90
82	·556	15·05	·31	·09	·05	235	260	305	120	40
90	·557	15·06	·53	·23	·10	249	263	305	145	82
81	·557	15·24	·47	·21	·09	227	229	247	135	74
89	·558	15·26	·51	·20	·11	230	241	273	129	57
70	·559	15·16	·47	·20	·11	250	260	290	150	100
72	·562	15·16	·39	·16	·09	220	225	235	125	65
62	(·563)	15·01	·07	·31	·07	252	208	333	206	63
86	·568	15·06	·41	·18	·08	237	249	266	135	85
34	·568	15·07	·47	·18	·11	241	272	302	120	61
61	·569	15·18	·48	·18	·10	241	246	280	146	83
91	·586	15·17	·42	·16	·06	241	247	278	145	85
39	·589	15·06	·62	·25	·13	235	252	281	128	44
30	·592	15·16	·38	·16	·09	217	223	237	121	54
11	·596	15·00	·53	·23	·15	224	224	236	134	76
3	·600	15·21	·40	·14	·07	225	230	256	130	59
21	·605	15·14	·42	·17	·08	232	237	263	137	73
20	·609	14·95	·43	·17	·10	230	242	260	128	70
45	·617	15·00	·44	·19	·11	218	226	239	120	55

TABLE III.—*continued.*

No.	Period.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d	m	m	m	m	°	°	°	°	°
35	(·617)	14·92	·01	·31	·02	254	272	241	146	161
26	·623	15·06	·42	·18	·13	225	231	241	129	74
16	·648	15·02	·57	·24	·11	231	239	267	133	66
43	·660	15·09	·34	·12	·05	248	290	352	116	32
75	·687	15·12	·30	·11	·06	221	233	256	119	47
9	·699	15·06	·50	·18	·11	231	254	291	118	42
66	(·702)	14·90	·00	·23	·01	(180)	231	97	(39)	83
87	·738	15·08	·21	·08	·03	228	256	270	110	54
77	·845	14·91	·29	·08	·04	238	271	320	115	34
42	25·74	11·77	·52	·13	·10	226	259	297	103	21
84	26·5	12·07	·57	·11	·09	228	285	320	81	4
50	106·0	13·71	·58	·18	·11	237	262	304	122	47

TABLE IIIa.

31	·231	15·02	·35	·01	·02	233	320	334	56	5
88	·247	15·14	·26	·02	·01	244	270	45	128	327
44	·248	14·95	·28	·03	·02	233	245	317	131	22
79	·250	14·89	·26	·02	·02	249	309	38	99	349
80	·252	15·00	·22	·04	·02	224	293	312	65	0
62	·281	15·01	·30	·03	·02	206	249	249	73	9
35	·308	14·92	·30	·02	·02	271	80	108	12	345
66	·351	14·90	·23	·04	·01	231	310	4	62	329

TABLE IV.—M15.

No.	Period.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3	ϕ_2.	ϕ_3.
	d	m	m	m	m	°	°	°	°	°
50	·299	15·76	·31	·11	·03	252	268	306	146	90
4	·314	15·67	·38	·07	·02	239	344	351	44	6
11	·344	15·75	·39	·12	·05	237	249	300	135	51
7	·349	15·89	·31	·07	·03	247	285	3	119	18
57	·349	15·63	·33	·05	·01	269	337	180	111	267
64	·352	15·93	·30	·07	·02	244	309	13	89	359
42	·360	15·77	·36	·08	·01	252	275	297	139	99
24	·370	15·78	·38	·09	·04	241	328	22	64	341
38	·375	15·74	·44	·08	·05	246	306	8	96	10
40	·377	15·72	·33	·08	·05	225	238	287	122	28

TABLE IV.—*continued.*

No.	Period.	m_3.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d		m	m	m	°	°	′	°	°
18	·378	15·80	·26	·07	·02	266	292	29	150	49
48	·379	15·80	·37	·08	·00	245	289	(225)	111	(150)
66	·379	15·77	·35	·04	·02	253	324	356	92	43
14	·382	15·72	·31	·04	·04	235	324	345	56	0
35	·384	15·71	·34	·09	·04	263	20	131	56	298
5	·385	15·69	·32	·09	·04	236	282	319	100	29
62	·388	15·97	·33	·05	·05	266	340	59	102	19
3	·389	15·71	·35	·08	·04	261	323	52	109	11
39	·390	15·74	·38	·11	·04	237	302	344	82	7
51	·398	15·79	·26	·07	·02	262	325	60	109	6
10	·398	15·79	·25	·06	·01	248	289	0	117	24
54	·398	15·84	·28	·06	·03	239	316	13	72	344
26	·402	14·66	·32	·07	·02	248	306	17	100	7
30	·406	15·71	·31	·05	·03	258	328	58	98	356
43	·407	15·62	·34	·07	·06	243	260	335	136	34
53	·414	15·64	·32	·07	·03	248	271	0	135	24
49	·418	15·17	·25	·12	·06	235	227	238	153	107
58	·420	16·01	·33	·08	·04	249	298	0	110	27
31	·436	15·68	·35	·10	·02	245	317	10	83	5
56	·570	15·81	·43	·19	·07	247	247	287	157	94
19	·572	15·72	·56	·24	·12	238	230	251	156	103
29	·574	15·72	·46	·16	·09	244	255	308	143	64
13	·575	15·85	·44	·21	·10	234	237	260	141	82
52	·576	15·89	·44	·22	·12	239	245	262	143	95
15	·584	15·76	·48	·13	·10	233	252	309	124	30
12	·593	15·79	·44	·16	·08	244	258	301	140	71
44	·596	15·85	·35	·17	·10	233	229	247	147	92
32	·605	15·71	·33	·16	·08	240	246	270	144	90
61	·610	15·91	·35	·14	·06	249	257	302	151	85
36	·624	15·88	·46	·19	·12	241	259	295	133	68
21	·625	15·81	·46	·14	·07	248	280	326	126	58
23	·633	15·64	·41	·15	·08	237	247	274	137	77
8	·646	15·83	·38	·17	·09	231	231	254	141	79
45	·662	15·90	·36	·19	·11	239	233	239	155	118
47	·663	15·78	·32	·11	·05	243	260	293	136	76

TABLE IV.—*continued.*

No.	Period.	m_0.	r_1.	r_2.	r_3.	θ_1.	θ_2.	θ_3.	ϕ_2.	ϕ_3.
	d		m	m	m					
2	·664	15·76	·31	·18	·09	254°	255°	269	163°	133
25	·665	15·75	·39	·18	·09	248	246	282	160	102
6	·666	15·91	·43	·22	·12	224	222	234	136	78
17	·667	15·76	·21	· 0	·05	250	253	268	157	122
28	·671	15·82	·40	·18	·09	236	243	268	139	80
63	·674	16·07	·42	·14	·06	234	255	300	123	42
60	·692	15·73	·36	·12	·07	241	250	307	142	56
46	·693	15·98	·40	·15	·10	238	271	300	115	54
16	·695	15·81	·17	·09	·05	230	248	263	122	67
20	·701	15·85	·37	·15	·09	236	250	287	132	61
9	·715	15·68	·37	·16	·08	245	256	293	144	82
55	·720	16·02	·35	·14	·07	230	238	259	132	71
22	·722	15·69	·34	·16	·08	230	257	290	113	40
65	·756	15·90	·34	·13	·07	244	272	308	126	64
1	1·437	15·06	·55	·17	·03	260	284	354	146	66

Note on Robert Jonckheere's Newest Pairs, Nos. 1035–1319.

By Eric Doolittle.

These stars were reduced to the epoch 1880·0, the identifications being taken from Jonckheere's *General Catalogue*, *Memoirs of the Royal Astronomical Society*, **61**, and were added to the extension of Burnham's *General Catalogue*. In the course of the work the following notes and corrections were suggested :—

No. 1041. *AB* is Argelander 97 :

1854·74 1ˢ·00 *p* 10″ *s* 9·5 9·5 Arg. in. Bonn. VI. "Class III."

1067. The R.A. is 1 min. too large.

1071. In the Index, page 196, Cat. No. should be 2691 instead of 269.

1109. The Decl. is 17′ too large.

1141. *AB* is Roe 16 :

1909·61 75°·4 6″·64 9·5 10·0 Roe 3n. *A.N.* 4381.

1147. The Decl. is 20′ too small.

1165. In the Note, Σ 402 should be OΣ 402.

1173. The Decl. is 10′ too small.

1244. This is Σ 2791, Burnham's G.C. No. **10946**.

No. 1248. This is Σ 2157, Burnham's G.C. No. 7986.

1270. If the identification is correct, the R.A. is 2 min. 13 secs. too small and the Decl. is 14′ too large. There is no BD star in R.J.'s position.

1220. Measured by Roe and thought to be new, but R.J.'s measure precedes:

1917·64 129°·3 1″·94 9·9 7·9 Roe 2n.

1319. The position agrees with that of BD 29°, 4317, and it is assumed that this is the star.

The Flower Observatory:
1919 *August* 15.

Erratum.

P. 372.—8th star, *for* U Cygni, 201647 *read* V Cygni, 203847.

LIST OF ADDITIONS

TO THE LIBRARY

OF THE SOCIETY

JUNE 1918 TO JUNE 1919.

An asterisk (*) indicates that the work is an excerpt.

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Boletin, Año 9, 10. (No. 81–90.)
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——: *On the dark markings in the sky. With a catalogue of 182 such objects.
(*Author.*) 8vo. Chicago, 1919

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